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THE CANADIAN FISH CULTURIST

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Correspondence should be addressed to the DIRECTOR, INFORMATION AND EDUCATIONAL SERVICE, DEPARTMENT OF FISHERIES, OTTAWA, CANADA.

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of
HON. J. ANGUS MACLEAN, M.P.,
Minister of Fisheries

The Robertson Creek Spawning Channel

by

K. C. Lucas

Department of Fisheries of Canada, Vancouver, B.C.

The largest salmon spawning channel constructed to date in Canada or the United States was put into partial operation in late October, 1959, at Robertson Creek, near Port Alberni, B.C. It is known as the Robertson Creek Spawning Channel, and was planned and constructed by engineers and biologists of the Fish Culture Development Branch of the Department of Fisheries of Canada. The object of this paper is to review the history, design considerations and construction features of this new spawning channel.

History of Spawning Channel Development

Man-made spawning channels are a very recent advance in the field of fisheries conservation and development. The two main advantages of spawning channels are: first, the survival of deposited eggs to emergent fry which occurs in natural spawning areas can be increased substantially by establishing stable and optimum physical conditions, and second, new spawning areas can be created where none previously existed. Under natural conditions the survival of Pacific salmon eggs and alevins varies widely, but is generally a small percentage of the number spawned. Royce (1959), in reviewing various investigations of egg to fry survival in Alaska and British Columbia, reported that on the average, less than 10 per cent of the eggs of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*) and sockeye (*O. nerka*) salmon hatch and leave the streams as free-swimming fry.

There are many factors which can limit survival of salmon eggs and alevins; however, the major causes of low survival which can be greatly reduced or virtually eliminated by the use of man-made spawning areas are as follows:

1. *Erosion of spawning beds.* Floods occurring after egg deposition often erode stream beds to such an extent as to uncover and wash away eggs and alevins. Hydrographs of typical southerly coastal streams of British Columbia invariably show the maximum freshets occurring in the months of November through January, therefore the problem of erosion of spawning beds is particularly evident there on streams with no appreciable natural lake storage to modify extreme runoff. Evidence from studies at Nile Creek by the Fisheries Research Board of Canada from 1947 to 1952 indicated that protection of the spawning beds from freshets could significantly increase egg to fry survival as reported by Wickett (1952).

2. *Silting of spawning beds.* Many normally clear salmon spawning streams become turbid with suspended silt during floods. Recession of these floods often results in the deposition of heavy layers of silt on spawning areas, thus reducing the rate of interchange of surface and subterranean water and hence lowering the amount of dissolved oxygen available to eggs in the gravel. The International Pacific Salmon Fisheries Commission carried out laboratory experiments in 1954 which demonstrated lower survival for sockeye eggs placed in gravel which was covered with silt (Personal communication).

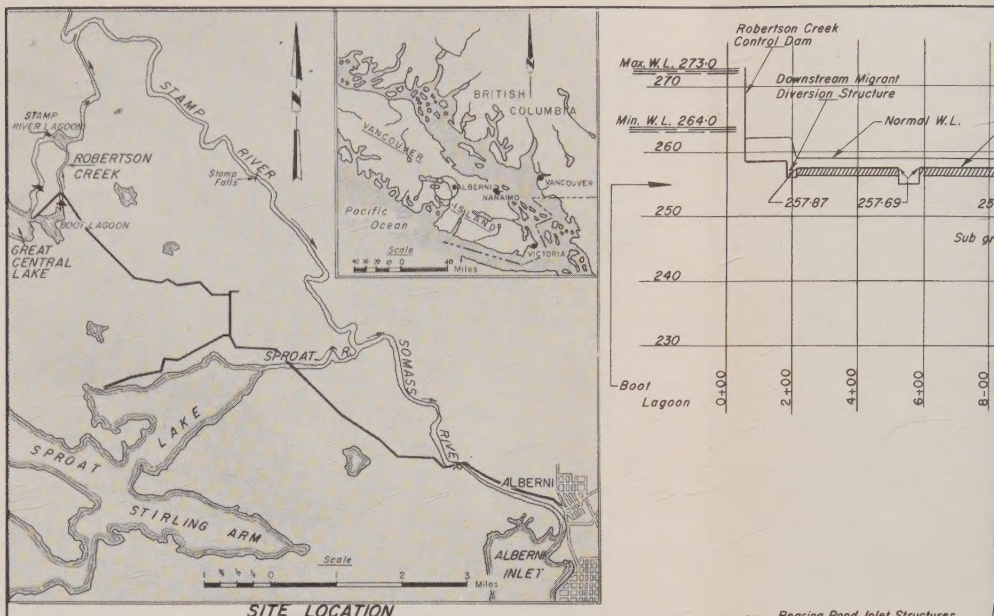
3. Lack of adequate flow through the gravel. The supply of dissolved oxygen to developing eggs and alevins depends on the percolation of subterranean flow through spawning beds. In streams, this subterranean flow is a function of the surface flow in the stream and the porosity of the gravel in the stream bed. As pointed out in (2) above, a covering of silt reduces sub-surface percolation, and a reduction in surface flow in a stream also reduces percolation. This latter point is important, as the flow in many British Columbia coastal streams becomes very low during relatively short, cold spells during the winter. The effects of low oxygen levels on developing eggs such as would be the case during temporary low flow periods, and a definition of critical levels of dissolved oxygen for egg survival are reported by Alderdice, Wickett and Brett (1958). Notwithstanding silting or low surface flows the porosity of stream gravels depends on its physical makeup, or *grading*, and can vary widely in nature. Areas of finer stream bed materials have a lower porosity and hence a slower rate of flow through the gravel. Wickett (1954) found by standpipe measurements that a low survival of chum salmon eggs was caused by low oxygen levels associated with a low percolation rate of water through the gravel. In choosing areas to spawn, salmon apparently use the more permeable areas of a stream bed; however, natural gradation of stream gravel probably does not provide optimum percolation in most areas. In the construction of spawning channels, the spawning gravel can be screened and washed to remove all fine material, and thus provide a much higher porosity than can be found in nature.

While it is recognized that there are many factors which can limit survival of salmon eggs and alevins, the elimination of the major physical factors outlined above is the primary aim in the construction of spawning channels.

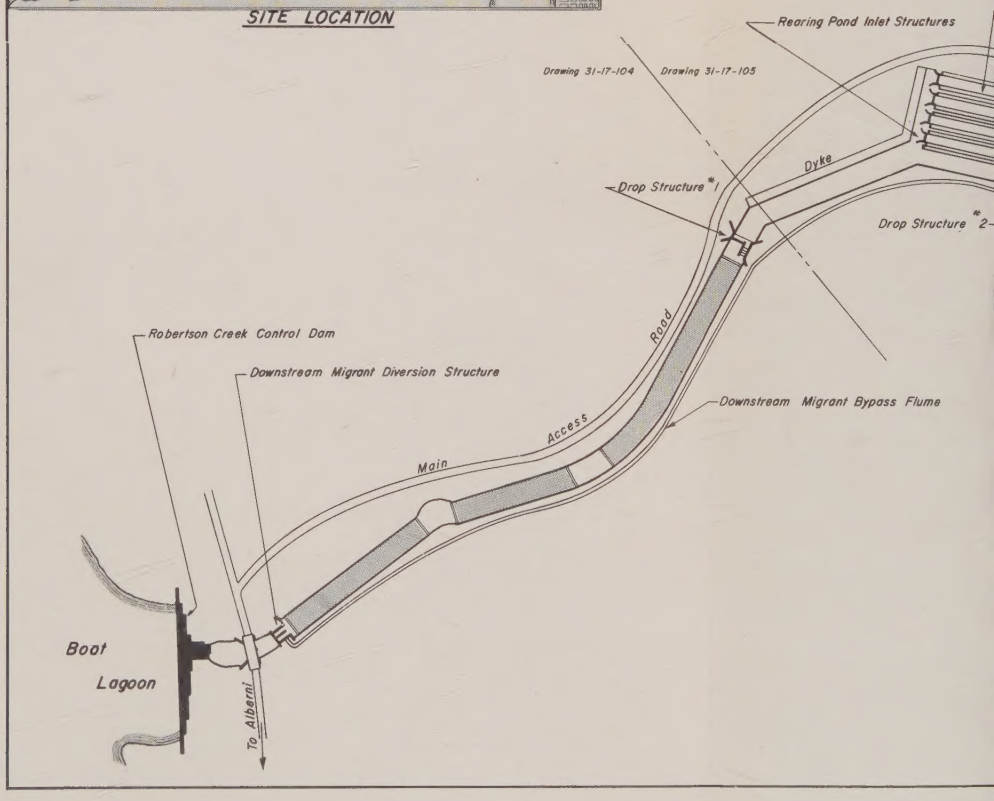
The first large man-made spawning channel was constructed at Jones Creek near Hope, B.C. in 1954. The Jones Creek spawning channel was built by the British Columbia Electric Company as a result of recommendations by engineers and biologists of the Fish Culture Development Branch for saving the stocks of fish in this stream in the face of a hydro-electric diversion from Jones (Wahleach) Lake. This channel, described by Hourston and MacKinnon (1957), is an artificial stream having a surface width of 14 feet and a length of 2000 feet. It carries an average flow of 20 c.f.s. and was constructed alongside the natural stream bed of Jones Creek. This natural stream bed was retained as a flood channel with a small headworks diverting flow into the new channel, and a weir located just above the spawning channel outlet directing all salmon into the new area. The channel gradient, depths of water, and gravel size were based on measurements recorded on natural spawning areas on several streams in British Columbia.

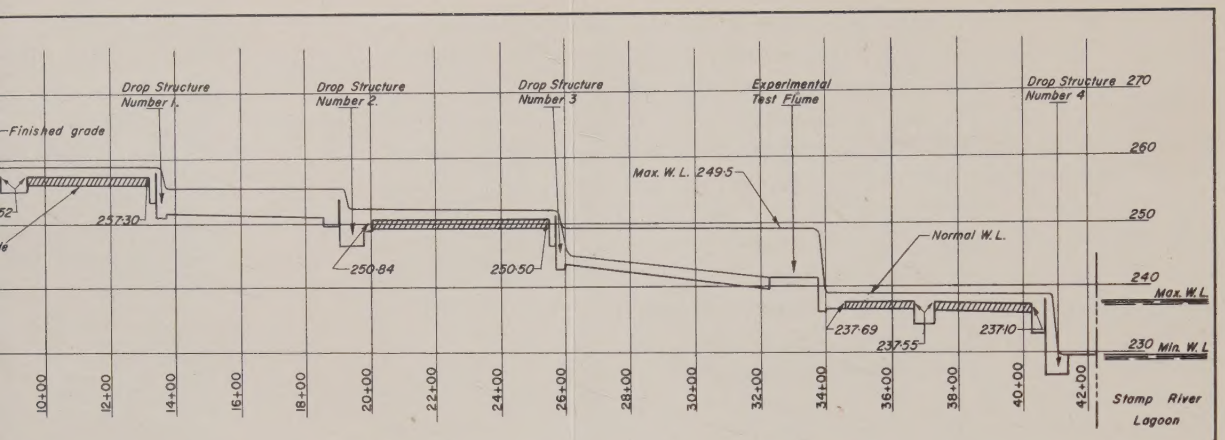
Complete biological studies of spawning, incubation, survival and downstream migration have been maintained at Jones Creek since completion of the spawning channel in 1954 (Hourston and MacKinnon, 1957). This stream is frequented primarily by pink salmon during the odd-numbered years and also by small numbers of chum salmon and coho salmon (*O. kisutch*) every year. Measured survival of potential egg deposition to migrating fry for pink salmon has been 36 per cent in 1955-56 and 38 per cent in 1957-58. The survival of pink salmon eggs to fry in an even-year planting experiment in the channel by the Fisheries Research Board of Canada in 1954-55, as described by Neave and Wickett (1955) was measured at 37 per cent.

FIGURE 1.—*Location Maps, general site plan and profile of the Robertson Creek spawning channel.*

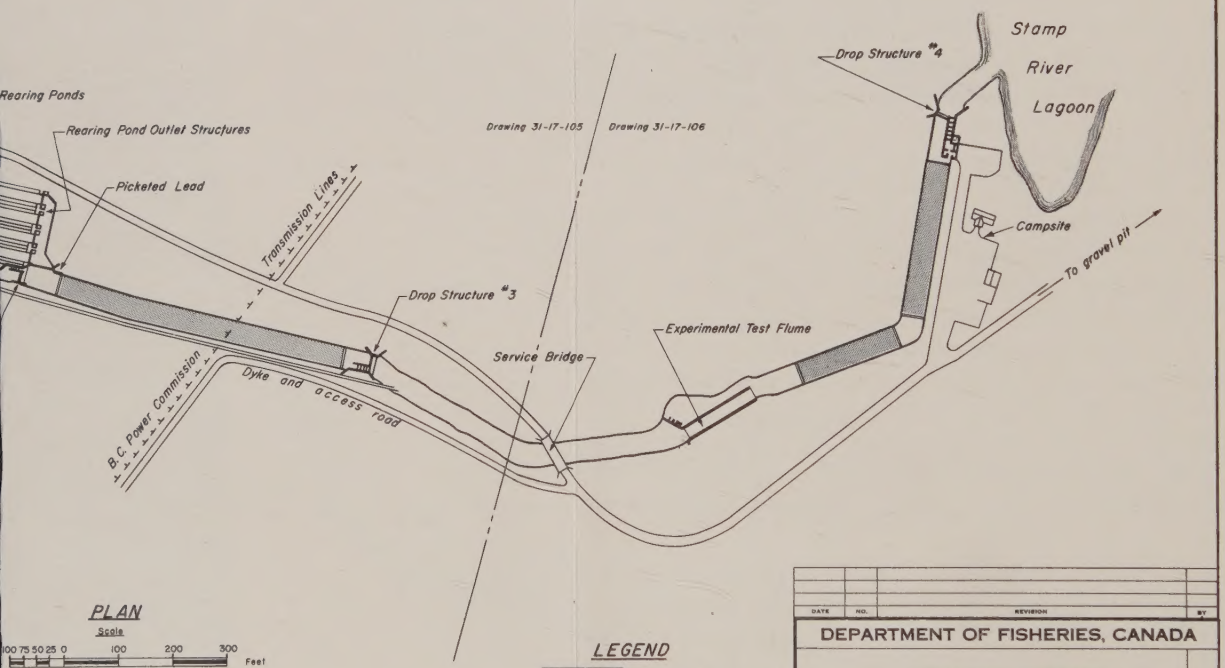


SITE LOCATION





PROFILE



PLAN

Scale

100 75 50 25 0 100 200 300 Feet

LEGEND

Spawning Areas

DATE	NO.	REVISION	BY

DEPARTMENT OF FISHERIES, CANADA

SPAWNING CHANNEL ROBERTSON CREEK LOCATION MAPS AND GENERAL SITE PLAN & PROFILE

31-17-103

DATE: 25 April, 1960	DRAWN:	SCALE: As shown
DESIGN:	CHECK:	
APPROVED: ENGINEER	CHIEF ENGINEER	DWG. NO. 31-17-103

The second sizeable spawning channel on the Pacific Coast was constructed in 1957 by the U. S. Army Corps of Engineers on the Oregon shore of the Columbia River immediately below McNary Dam. This channel was designed to carry out research of the production of fall chinook (spring) salmon (*O. tshawytscha*) in artificially created spawning areas as a means to provide compensation for losses of fish at dams. It is operated by the Washington State Department of Fisheries under a contract with the Corps of Engineers. The McNary spawning channel has a water surface width of 31 feet, a length of 2545 feet and carries an average flow of 60 c.f.s. Water supply for the channel is by pipeline from the dam and the channel discharges into the Columbia River. The channel water depths, velocity and gravel composition were based on a study of salmon spawning grounds in natural areas carried out from 1953 to 1955 by the Washington State Department of Fisheries (Chambers, Allen and Pressey, 1955). No definite information on egg survival has been published, however the channel is apparently operating with some success (personal communication). A detailed description of the facilities and their operation is given in the Annual Report of the Washington State Department of Fisheries 1958.

The Robertson Creek project is then the third large spawning channel to be constructed on the Pacific Coast of North America. However it is the first such channel to be constructed primarily as a fisheries development project (i.e. extension of natural spawning grounds) rather than a fish salvage or research operation in conjunction with hydro-electric power development.

Development of Flow Control on Robertson Creek

Robertson Creek is a secondary outlet of Great Central Lake near Port Alberni, B.C. (See site location map on Figure 1), the primary outlet being the Stamp River which flows southerly into the Somass River and thence into Alberni Inlet, on the west coast of Vancouver Island. Robertson Creek joins the Stamp River about one mile downstream from Great Central Lake.

In its natural state Robertson Creek, also known locally as Robson Creek, was not a perennial stream but only flowed when the water surface of Great Central Lake rose above elevation 263.5 (geodetic). This elevation corresponded to a flow of about 2500 c.f.s. at the Stamp River outlet. A review of past water records at Great Central Lake Stamp River outlet shows that Robertson Creek in its natural state only carried water a total of three months in any one year, and then only a maximum of two months continuously.

About 1923 a logging control dam was constructed at the Stamp River outlet of Great Central Lake which controlled lake levels in the approximate range of elevations 262 to 269. This dam enabled logs to be floated to a large sawmill which was operated on Boot Lagoon (Figure 1) in the 1920's, and after a fire destroyed this mill the dam was apparently not operated and fell into disrepair. Water flowed more frequently in Robertson Creek after construction of this dam; however, there were still dry periods when flows were interrupted, and also freshet periods when floods caused by high lake levels swept down the relatively narrow, steep little creek.

Meanwhile an expansion of the sulphate pulp mill at Alberni in 1956 made necessary the provision of water storage in Great Central Lake to supplement low summer

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flows to prevent pollution at the mouth of the Somass River by pulp mill wastes. In 1957 the old dam at the Great Central Lake outlet was replaced with a higher and more permanent concrete structure incorporating an extensive fishway system. Since storage levels in the lake were to be raised to a maximum of elev. 273, a dam was also built at the upstream end of Robertson Creek to provide control of flows there. This dam was built of treated timber and had incorporated a small fishway and a flow outlet works designed to pass a continuous flow in Robertson Creek of about 50 c.f.s.

Indigenous Fish Populations

Although no definite records are available, Department field personnel have reported spawning of small numbers of coho and spring salmon in Robertson Creek in most recent years. It may be assumed that recently the creek provided spawning area for 100-500 coho and spring salmon and also served as a migration route for a small number of coho into Great Central Lake. The largest number of spawning fish actually recorded in Robertson Creek was 550 coho and 100 spring salmon in 1956. A biological survey on this year reported that there were only two areas where suitable spawning gravel occurred, viz. 75 yards of stream at the extreme upstream portion and a 100-yard reach immediately above the creek mouth. Both these areas were heavily spawned in 1956, with the upper area used exclusively by coho and the lower area by coho and springs.

It was for the protection of these runs of fish, which must have been built up since the original dam construction about 1923, that provisions for a continuous flow release and upstream fish passage were made in the Robertson Creek Control dam built in 1957.

Objectives and Development of a Spawning Channel at Robertson Creek

With the completion of the Robertson Creek dam and flow control works in the fall of 1957, Robertson Creek became a perennial stream for the first time in its history. It became apparent to the Fish Culture Development Branch that Robertson Creek was ideally suited as a site for a man-made spawning channel since works for the complete control of flows already existed, no provision for flood flows had to be made, no serious silting problem from inflow water was anticipated, temperature of the stream remained moderate and the area was readily accessible.

In the light of the facilities and favourable conditions available, it was felt the Department of Fisheries would be remiss in not taking full advantage of the situation in order to accomplish two major objectives. The first of these was to work towards the solution of fisheries problems associated with the proposed Somass River system hydro-electric power development, particularly on the problems of requirements for rearing pre-migratory spring and coho salmon and replacing natural spawning areas of these same species with artificial areas. The second was to institute a fisheries development project aimed at (a) introducing and supporting runs of pink salmon in the Upper Somass River sytem, and (b) increasing the present minor numbers of coho and spring salmon to the full potential of Robertson Creek.

Preliminary design of a channel to carry a flow of 50 c.f.s. was begun early in the fall of 1958. However the concurrent design of another project, an experimental test

flume on the same creek described later in this report, dictated an increase in the average design flow to 100 c.f.s. Maximum design flow capacity of the channel was finally set at 250 c.f.s. as governed by the requirements at the test flume.

A total of $150,000 was spent on construction of the Robertson Creek channel in 1959. This amount provided for the completion of all subaqueous channel facilities and almost all control structures, thus enabling the channel to be put into operation at reduced flows in October, 1959. A further $90,000 will be spent in 1960 to add an additional control structure at the entrance of the channel incorporating a fish trapping works, to provide appurtenant experimental fry rearing channels, and to construct a downstream migrant bypass system parallel to a portion of the channel. By October 1, 1960 it is anticipated that all major works on the channel will be complete and in operation, and a normal channel flow of 100 c.f.s. will be maintained after that time.

The following sections of this report will deal with the detailed description of the channel works, including design considerations. The reader should refer to the general site plan of the channel on Figure 1 in following this description of works.

Spawning Channel

The total length of Robertson Creek from the dam at its upstream end to the Stamp River at its lower end is 4200 feet. Twenty-five hundred and fifty feet of this length has been developed as spawning channel and the remainder is taken up by the control structures, rearing ponds, experimental flume, bypass and fish transportation channels. The gradient of the natural stream bed was substantially greater than was required for the spawning channel, therefore several drop structures were provided to localize the unwanted extra drop.

The hydraulic design criteria for the spawning channel cross-section were as follows:

1. Normal channel flow during spawning period to be 100 c.f.s.

2. Average velocity and depth of water in the channel at 100 c.f.s. discharge to be 1.5 f.p.s. and 1.5 feet, respectively. However provision to vary these amounts by at least 50 per cent to be provided.

3. Maximum water depth to be 2.5 feet.

4. Maximum discharge capacity of channel, governed by test flume studies, to be 250 c.f.s.

A uniform trapezoidal cross-section was chosen having a bottom width of 35 feet and side slopes of 2:1 (Figure 2). Thus the water surface width at normal flow will be 41 feet. The value of Kutter's or Manning's roughness coefficient n for the channel was assumed to be in the range 0.023–0.025 for water depths in the range of 2.5 to 1.0 feet based on laboratory measurements made for the McNary spawning channel (Webb and McKinley, 1955). A channel bottom slope of 0.0006 was chosen, which is slightly steeper than the predicted water surface slope of 0.0004 calculated for uniform flow. It was suspected that the channel might be slightly rougher than the design assumption allowed, and in any case it was considered to be preferable to have the flexibility of flow control remain at the drop structure rather than depend wholly on channel parameters.

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The variation of channel depth is accomplished by manipulating adjustable sector gates on the drop structure crests, and the average velocity in the channel for a given depth will be varied by altering the discharge in the channel by operating the gates at the control dam.

The channel side dykes have a minimum height of three feet above channel bottom, giving a freeboard of six inches at maximum discharge. The maximum average velocity in the channel when it is carrying the peak discharge of 250 c.f.s. will be 2.5 f.p.s.

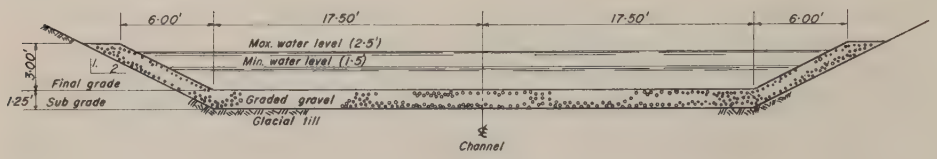

FIGURE 2.—*A typical cross-section of the spawning channel.*

The drop structures divide the spawning channel into three sections. The upper section, extending from the downstream migrant diversion structure to drop structure No. 1 is 1150 feet long. This section contains three holding pools for fish: one immediately upstream of the drop structure and two at bends in channel alignment. These pools are about 40 feet long and five feet deep. The middle spawning channel section is between drop structures No. 2 and No. 3 and is 650 feet long. The two holding pools in this section are located immediately upstream of drop structure No. 3, and immediately downstream of drop structure No. 2. The lower spawning channel section is located between the experimental test flume and drop structure No. 4 at the mouth of the creek. This section is 750 feet long and contains three holding pools: one just upstream of drop structure No. 4, one at a bend in the channel and one immediately below the test flume. Hence the Robertson Creek channel actually consists of three sections of channel, and although each must carry the same discharge as released from the Robertson Creek control dam, the water depth and velocity in each section may be individually controlled within certain limits by the adjustable gates on the crest of each drop structure.

The right-of-way of the spawning channel generally followed the old creek bed, however considerable clearing and excavation was required to prepare the channel subgrade. Figure 3 shows a section of the channel right-of-way before work began and Figure 4 shows a section excavated to subgrade.

The spawning gravel has been placed directly on the channel subgrade, which is composed of an impervious glacial till in most areas. The spawning gravel in the upper and middle sections of the channel was placed to a minimum depth of 15 inches, while in the lower section the depth was increased to 20 inches, since this section is tentatively planned for use by spring salmon, the largest species. Figure 5 shows the spawning gravel in place in the upper section of the channel. The spawning gravel was specified to lie within certain limits on a grading curve (Figure 6), with 100 per cent passing a 4″ screen and 100 per cent retained on a $\frac{3}{4}$″ sieve. The 4700 cubic yards of gravel required for the channel was washed and screened at a pit near Alberni, 13 miles from Robertson Creek.

FIGURE 3.—*Channel right-of-way looking downstream towards site of rearing ponds bypass channel before construction.*

FIGURE 4.—*Channel excavated to subgrade upstream of drop structure no. 4.*

FIGURE 5.—*Spawning gravel in place in upstream section of spawning channel. Note holding pool at bend in foreground and invert controls.*

The gravel grading curve for the Robertson Creek channel was a refinement of the grading curve recommended for the Jones Creek spawning channel. Experience at Jones Creek showed that natural erosion and silting very quickly added fine material to the original screened material placed in the spawning channel, and the channel had soon become quite consolidated with resulting lower sub-surface percolation rates. As a result, the Jones Creek channel bed has had to be loosened and flushed almost every year and in 1959, only five years after it was first constructed, the gravel was completely removed, screened, washed and replaced. Hence, in designing the spawning gravel grading curve for the Robertson Creek channel, the upper (coarse) limit of the Jones Creek curve was maintained but the lower (fine) limit was drastically curtailed. The Jones Creek spawning channel gravel grading curve is reproduced in Figure 6 for comparative purposes.

One other feature of the spawning channel is the provision of invert controls at intervals on the channel bottom to control erosion and movement of the spawning bed. These invert controls are constructed of pressure-treated 6″ × 6″ timber members supported on posts driven firmly into the channel subgrade. The tops of the invert controls are flush with the finished grade of the spawning gravel and since they are suspended 9 to 14 inches above the subgrade, they do not interfere with subsurface water percolation in the spawning gravel. These timber invert controls are provided at each end of the holding pools, and are also installed at maximum intervals of 200 feet on all tangents. Figure 7 shows the invert controls being placed in position before the spawning gravel was laid.

A typical section of spawning channel as it appears with a flow of 100 c.f.s. is shown in Figure 8.

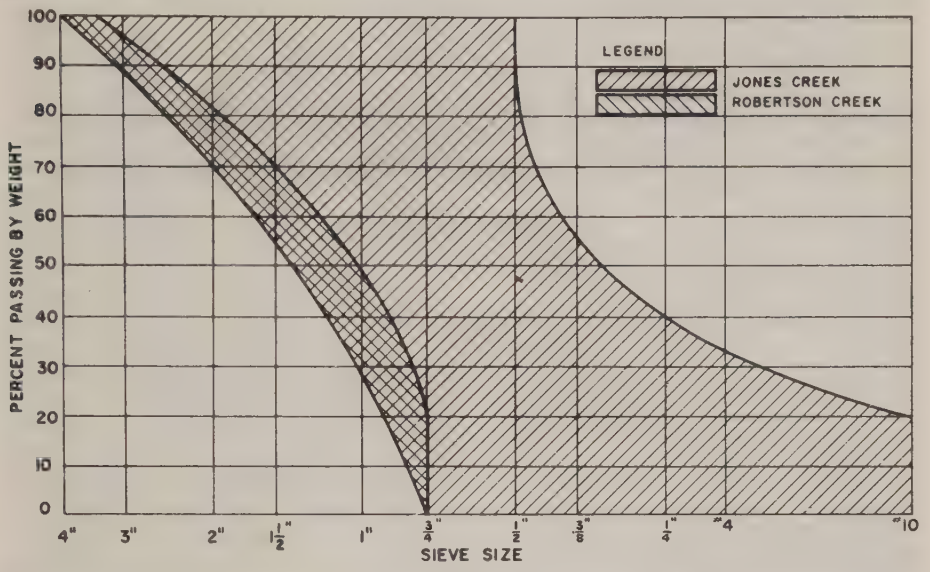

FIGURE 6.—*Grading Curve limits of spawning gravel at Robertson Creek and Jones Creek spawning channels.*

Drop Structures

As mentioned earlier, it was necessary to provide a total of four drop structures at intervals along the channel to localize the excess drop in the creek gradient.

Drop structures Nos. 1, 2 and 3 are very similar in design. The water surface drop at structures No. 1 and No. 2 is three feet, and at drop structure No. 3 varies from $2\frac{1}{2}$ to $5\frac{1}{2}$ feet, depending on the backwater effects from the experimental flume. They are constructed of reinforced concrete and consist of a large base slab from which are cantilevered the walls of the structure. The base slab is designed as a spread footing with full hydraulic uplift assumed. Prevention of sliding and control of underseepage at drop structure No. 1 is handled by a keyway and dowels into bedrock and at structure No. 2 by a concrete cutoff wall cut into the glacial till, while at drop structure No. 3 it was necessary to use interlocking steel sheet piling driven a minimum distance of ten feet below the base slab to meet this problem.

The drop, or crest, wall at each structure is 20 feet long and is divided into two sections by a centre pier. A pair of steel sector gates are affixed to the top of the crest wall to control the depth of flow in the channel reach upstream. When fully lowered, the top of these gates is the same elevation as the invert of the spawning channel immediately upstream. The gates can be raised a maximum of 14 inches from the fully lowered position by manually operated cranks which move a tandem coupled pair of rack and pinion mechanisms located at each end of the gates. Each gate is operated individually to allow finer hydraulic control. Rubber seals are supplied at the sides and bottom of the gates to prevent excess leakage and prevent any loss of fry. Figure 9 is a perspective view of a typical drop structure crest wall showing the sector gates and gate-lifting mechanisms.

FIGURE 7.—*Invert Controls being placed in position in middle spawning channel. Centre section removed to allow passage of gravel trucks.*

FIGURE 8.—*Looking downstream at completed upper spawning area with channel discharge at 100 cfs.*

Stoplog guides are located upstream of the gates on the crest wall to allow the insertion of vertical fish retaining screens to keep adult fish from leaving or entering each channel section when it is desired to hold them in certain sections. The stoplog guides will also allow the dewatering of one of the gates for maintenance or repair while channel flows are maintained through the second gate.

Inclined plane traps capable of passing the maximum channel flow of 250 c.f.s. are planned for all drop structures to provide for the collection and enumeration of downstream migrant juvenile fish. These traps will be fastened to the downstream side of the drop structure crests. Permanent livebox pits have been provided at each drop structure for the collection of downstream migrants from the inclined plane traps.

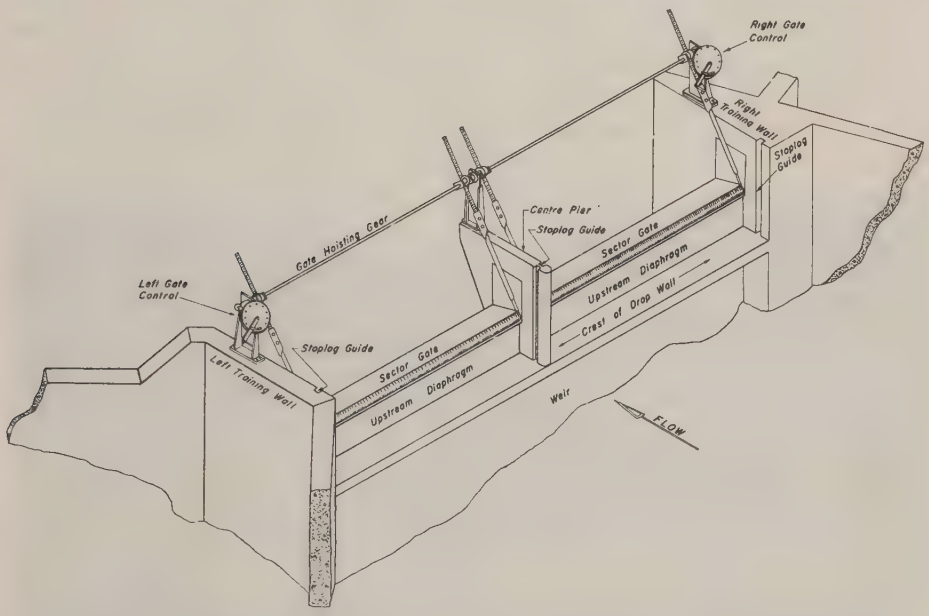

FIGURE 9.—*Typical crest wall of a drop structure showing sector gates and gate-lifting mechanisms.*

Each drop structure has been equipped with a pool and weir type fishway to provide for the natural migration of adult fish between each spawning section, if desired. Fish holding and collection works are also provided at drop structure No. 4, and these are described later. Fishways with four baffles each are provided at drop structures No. 1 and No. 2, while the fishways at drop structures No. 3 and No. 4 have five and nine baffles, respectively. Fishway pool size is six feet wide and eight feet long, with a four-foot minimum depth and a maximum pool differential of one foot. The concrete walls of the fishways are supplied with stoplog guides at baffle locations, and manually adjustable steel stoplogs are used to form the baffle weirs.

The fishway at each drop structure will also serve as a flow diversion channel if it is found necessary to dewater both sector gates or the weir crest of a drop structure without interrupting flow in the whole spawning channel.

A rock-paved stilling basin is provided below each drop structure to dissipate the hydraulic energy of the fall. Figure 10 shows a photograph of a typical drop structure in the upper sections of the spawning channel.

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Drop structure No. 4 at the mouth of Robertson Creek is much larger than the other three structures and it also incorporates a fish holding and collection system. The water surface drop at this structure varies from $1\frac{1}{2}$ to $8\frac{1}{2}$ feet, depending on the stage of the Stamp River, which controls the water level at the mouth of the Creek. The normal water-surface drop at this point is about six feet. This drop structure and appurtenances is constructed of reinforced concrete and is of the same general design as the other three structures. The foundation at this point is gravel, and a steel sheet pile cutoff wall is provided to prevent sliding and underseepage. The crest of the drop wall is provided with the same type of adjustable sector gates as the other structures, however the drop wall, or weir, is skewed at an angle of 20 degrees from the perpendicular to the channel centreline to provide a more attractive flow pattern to the fishway entrance for fish approaching the drop structure. Since the water-surface drop over the structure will not always be sufficient to prevent fish from ascending into the channel by leaping over the weir, fish will be forced to use the fishway as their migration route by the provision of a blocking device on the drop structure crest in the form of an inclined plane screen which will also be used for enumeration of downstream migrant fish.

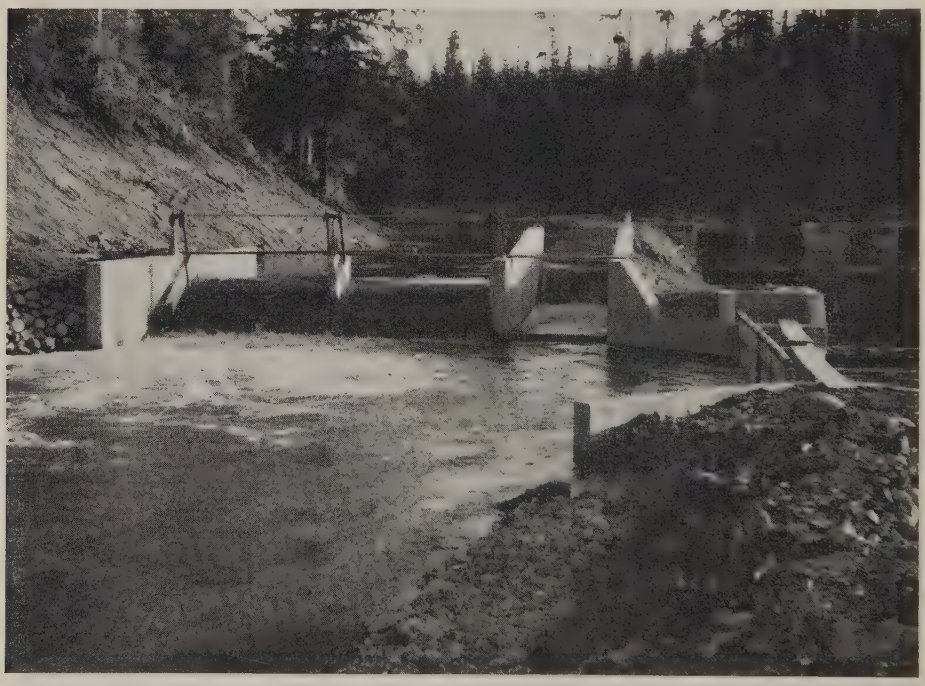

FIGURE 10.—*Drop structure No. 2 at a channel discharge of 100 cfs. Fishway not in operation.*

The fishway facilities at drop structure No. 4 are designed to either pass upstream migrant fish right through the structure and into the lower spawning channel, or to hold and collect these fish for transfer into a tank truck and thus enable placing of desired numbers, species, etc. into any of the three spawning areas.

Figure 11 shows an outline plan of drop structure No. 4. It can be seen that this structure is very similar to the other three as far upstream as fishway baffle 7, where the fishway broadens out into a combined holding and brail pool. At baffle 7 a finger

trap on the weir crest prevents adult fish from returning downstream. In the case where free movement of upstream migrating fish into the channel is desired, fishway baffles 8 and 9 will be in position and all fishway flow will originate from the fish exit. For the case when it is wished to collect fish for transfer to a tank truck, which is likely to be the case most of the time, all of the fishway flow will be admitted through a floor diffuser in the holding pool as regulated by a separate intake system.

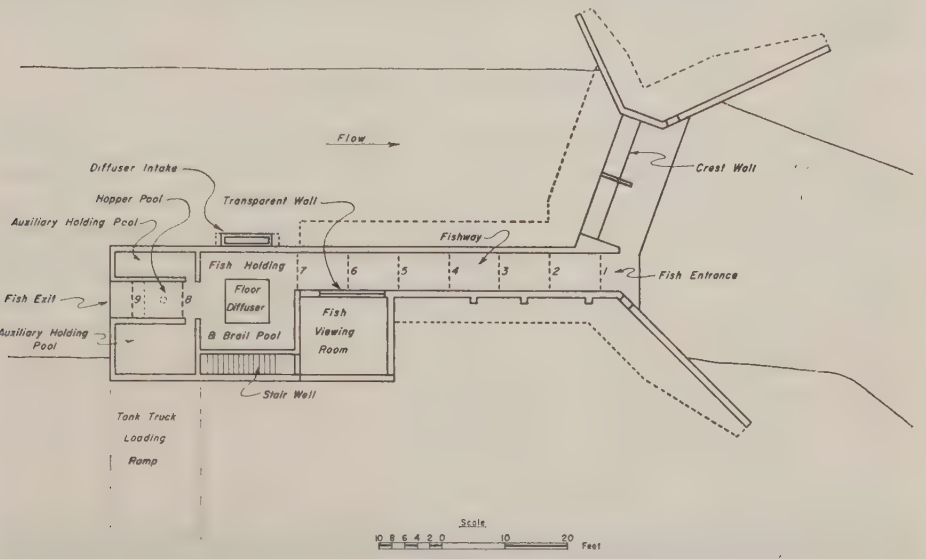

FIGURE 11.—*Outline plan of drop structure No. 4.*

The fish collection system is a simplification of those systems already used at several locations, such as on the Capilano River. The 15-foot square holding pool is equipped with an electrically-hoisted brail. The fishway between baffles 8 and 9 becomes the hopper pool and a steel superstructure carries an electric hoist and monorail enabling the raising and lowering of a six-foot square fish hopper from the fishway to a tank truck. When fish are to be moved from the holding pool, the brail will be raised and flow will be introduced into the hopper pool to create an attractive current. A system of screen gates between the brailing pool and the hopper pool will also enable the directing of fish into auxiliary holding pools in case sorting of several species of fish is required. Fish from these two auxiliary holding pools can later be transferred to the fish hopper by the operation of crowders and brails provided in these smaller pools. The designers have attempted to provide as much flexibility as possible in these facilities to provide for possible future experimental work, in addition to the more straightforward development requirements.

One additional feature of drop structure No. 4 which should be mentioned is the provision of a fishway viewing window on one side of one and one-half pools of the fishway. A closed-in fishway viewing room has been provided adjacent to this window. The window consists of a series of panels of one-inch thick acrylic plastic set in a structural steel frame. Provision has been made to replace the plastic with steel plate when the window is not in use. The purpose of the window is to allow the study of the relation of fish passage in the fishway to the hydraulics of various types of fishway

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baffles. The window covers a full wall of the fishway for one pool length downstream of a baffle, and one-half a pool length upstream. The stoplog guide provided at the baffle location will allow an easy interchange of various baffle types. It is expected that all-orifice fishway baffles will mainly be studied since observation will not be hampered by entrained air in the water. The fish viewing room is 14 feet long, which will allow the use of cinematography to record observations. A sump pump is provided to control seepage and a ventilation system will be used to control water condensation on the windows.

Flow Control Works

All flow through the spawning channel is controlled at the Robertson Creek dam. As mentioned previously this dam was constructed in 1957 by the MacMillan, Bloedel and Powell River Company in connection with the storage of water in Great Central Lake. The original outlet works at this dam provided a minimum discharge capacity of 35 c.f.s. at lowest lake levels through a 30-inch diameter gated pipe. To increase this minimum capacity to at least 100 c.f.s. at lowest lake levels and 250 c.f.s. at normal levels, the Department of Fisheries constructed an additional 48-inch diameter gated pipeline through the dam. This new pipe was constructed on the floor of the fishway at the dam, and since this fishway had a generous depth, it was possible to retain the fishway in good working order in the redevelopment at this site. A concrete apron was provided at the outlet of the new pipe to protect the toe of the dam from erosion by the enlarged flow. The Robertson Creek control dam may be seen in Figure 12.

FIGURE 12.—*Aerial view of the upstream end of the spawning channel showing the control dam in the foreground, the highway bridge, the partially built downstream migrant diversion structure and a portion of the upper spawning channel.*

Downstream Migrant Diversion Structure and Flume

The downstream migrant diversion structure is located about 150 feet downstream of the Robertson Creek control dam, just below the highway bridge across the channel. The purpose of this structure is to prevent any downstream migrating fish which come through the outlet works at the dam from passing into the spawning channel proper and thus adulterating experimental stocks of fish. Large annual downstream migrations of sockeye and coho salmon yearlings have used this route in leaving Great Central Lake in recent years, and it is expected that their numbers will increase in the future with higher flows in Robertson Creek. The lake is also populated with steelhead trout (*Salmo gairdnerii gairdnerii*) and many other species of freshwater fish, thus the exclusion of these from the channel is also important to prevent predation on young salmon fry.

The fish diversion structure basically consists of two parallel reinforced concrete flumes, each containing a large inclined screen. The stream flow passes downwards through the screens and then passes through two large rectangular sluicegates set in the weir at the downstream end of the structure. The head on these sluicegates is two feet, or in other words the water surface drop over the structure is two feet. The upward inclined screens are each ten feet wide and 13½ feet long, and are each made up of 30-inch wide by 10-foot long screen panels which can be individually rotated through 180 degrees to allow cleaning by backflushing action. About 10 c.f.s. of flow containing the downstream migrant fish will pass over the crest of the upstream screen where it will then fall through an inclined plane trap supplied with manually adjustable shutters. This trap will be operated so that not more than five c.f.s. of flow will be allowed into the collection trough along with the downstream migrants. Flow from the collection trough is led to a downstream migrant diversion flume which will be explained below.

The downstream migrant diversion structure design is based on the principles of the floating inclined plane trap or "scoop net" which is commonly and successfully used by biologists on the Pacific Coast for sampling runs of downstream migrant fish. The reason for passing more water than is needed for diversion over the crest of the trap screens and then providing an adjustable inclined plane trap to obtain just the required amount of flow for the bypass flume, is to overcome the problem of gross flow changes over the screen crest caused by partial clogging of the screens by debris between cleanings. The downstream migrant diversion structure can be seen in Figure 12.

In order to pass the downstream migrant fish around a portion of the spawning areas, a diversion flume is provided on the right bank of the spawning channel. This structure is a 30-inch diameter semicircular woodstave flume which is designed to carry a maximum flow of five c.f.s. A concrete transition section directs the flow from the collection trough of the downstream migrant diversion structure into the flume. The diversion flume is 2330 feet long and terminates just downstream of drop structure No. 3 where it spills into a stilling basin. It is necessary to return the downstream migrants to Robertson Creek at that point so that the sockeye and coho smolts in particular can pass on downstream through the experimental test flume where they are required for guiding studies. The fish pass through 600 feet of natural unimproved creek channel between the end of the diversion flume and the experimental test flume.

Thus downstream migrants entering Robertson Creek from Great Central Lake are bypassed around the upper and middle spawning sections, but do pass through the

lower spawning area. If required in the future, a diversion flume could be built from the inclined plane traps at the end of the experimental flume to the mouth of the creek to bypass the lower spawning area.

Experimental Rearing Facilities

Experimental rearing facilities are provided between drop structures No. 1 and No. 2 to enable study of the problem of rearing pre-migratory young salmon. The rearing sub-channels are so designed that they may also be used as small spawning channels for studies of adult spawning, or to provide a location for egg plants.

Permanent concrete inlet and outlet works are supplied for the rearing area, which has gross dimensions of 206 feet in length by 140 feet in width. This area will be sub-divided by gravel and earth dykes into four parallel sub-channels, or ponds. The adjustable weir crest at drop structure No. 2 and the individual pond inlet works provide a very flexible hydraulic control which will enable the diversion of any portion of the channel flow through these ponds. Screens at the inlet works will prevent the entry of any outside fish to the ponds and screens and inclined traps at the pond outlet works enable retention of fish in the sub-channels or enumeration of their emigrations. The total water surface drop through the rearing area inlets and outlets is three feet. Figure 13 shows a photograph of the experimental rearing facilities partially constructed.

FIGURE 13.—*Aerial view of partially constructed experimental rearing facilities looking downstream. Drop structure no. 2 at centre and middle spawning channel at top centre.*

Each of the four sub-channels is about 200 feet long and 20 feet wide. Provision has been made to make each of these channels divisible longitudinally into two equal parallel channels 200 feet long by 10 feet wide by the erection of a temporary centre partition. Provision has also been made for four lateral subdivisions in each pond to form four 50-foot long sections in either 20 or 10-foot widths. Timber beams resting on concrete footings have been provided on the sub-base of the rearing areas for these possible future divisions.

The sub-grade of the four sub-channels will be formed between earthen dykes, and 15-18 inches of standard spawning gravel, similar to that used in the regular spawning channel, will be placed on the sub-channel bottom and sides. Sub-channels Nos. 1, 2 and 3 are designed to carry a normal water depth of one and one-half feet, while sub-channel No. 4 has a normal water depth of three feet, nine inches. Figure 14 shows a plan of the experimental rearing area with the four sub-channel layout.

All these experimental installations are designed to have maximum flexibility so that a large range of studies can be made with a minimum of modification. However, if gross modifications were ever required, the rearing areas could easily be dewatered and the whole area excavated and redesigned without endangering the spawning channels downstream with silt, or interrupting the water supply.

Miscellaneous Structures and Works

Since the spawning channel passes underneath the Department of Highways bridge over Robertson Creek, revisions had to be made to the stream bed under the bridge to increase the discharge capacity of the channel. The two timber box culverts under the bridge were removed, the stream bed deepened several feet and a twenty-foot wide concrete flume structure built to protect the bridge pile bents from erosion. This revision can be seen in Figure 12.

A service bridge had to be built across the spawning channel about 1000 feet upstream of the mouth of the creek to provide access to the lower one-third of the channel. A thirty-foot span glue-laminated beam bridge designed for H-20 loading (20 tons) spanning between concrete abutments was constructed for this purpose.

A 700-foot long dyke and access road was constructed on the right bank of Robertson Creek upstream of the new service bridge. The dyke was necessary to prevent flooding of a large bush area adjacent to the channel, and the road on top of the dyke replaces the flooded-out access road along the B.C. Power Commission's Ash River transmission line which crosses the spawning channel at about its mid-point.

A chain-link security fence and gate are provided around the upstream end of the spawning channel to restrict vehicular traffic along the channel and to discourage unauthorized persons from tampering with equipment and works. It is eventually planned to place a shelter for a watchman-maintenance man at the gate when the biological programme at the channel fills out.

The 400-foot section of channel between drop structure No. 1 and the rearing pond inlets could not be developed into a spawning section because of unfavourable soil conditions. This area was formerly a swampy section of the creek and when channel excavation commenced it was discovered that this whole area consisted of rotted sawdust over ten feet thick in places. Obviously this material originated from the former

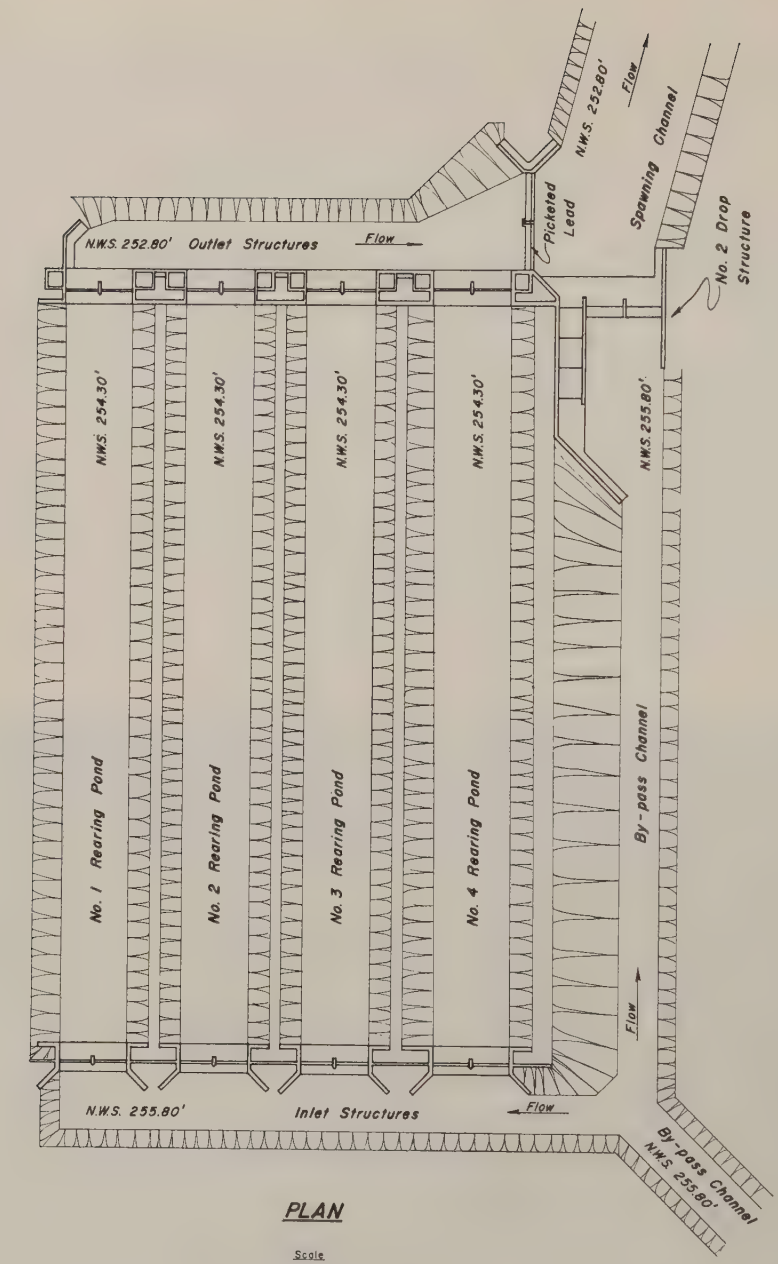

FIGURE 14.—*Plan and typical cross-section of experimental rearing facilities with four sub-channel layout.*

sawmill on Boot Lagoon. When no firm ground could be found on which to build a spawning channel, it was decided to merely excavate a deep bypass channel through this area, dimensioned so that average water velocities would not exceed one foot per second and thus prevent erosion. Excavation in this area proved to be very difficult, with large pads having to be used under all machines.

Since the discharge from the rearing area sub-channels would naturally attract upstream migrating adult fish, a picketed lead, or barrier, was constructed across the exit of the rearing pond outlets discharge channel. The picketed lead consists of a concrete base and piers supporting a vertical steel rack with the individual pickets angled so as to lead upstream migrants towards the fishway entrance at drop structure No. 2. The picketed barrier may be seen on Figures 13 and 14.

Experimental Test Flume

This structure, located about midway between drop structures No. 3 and No. 4, is not considered a part of the Robertson Creek Spawning Channel facilities. However it is mentioned here because its presence has governed the design of the spawning channel to a certain extent.

The test flume project was conceived one year before the spawning channel was proposed, however, when it was decided to proceed with the spawning channel, the construction of the two projects were integrated. The Fish Culture Development Branch has constructed the flume, however, the Fisheries Research Board of Canada has assumed about a one-third portion of the project's $72,000 cost.

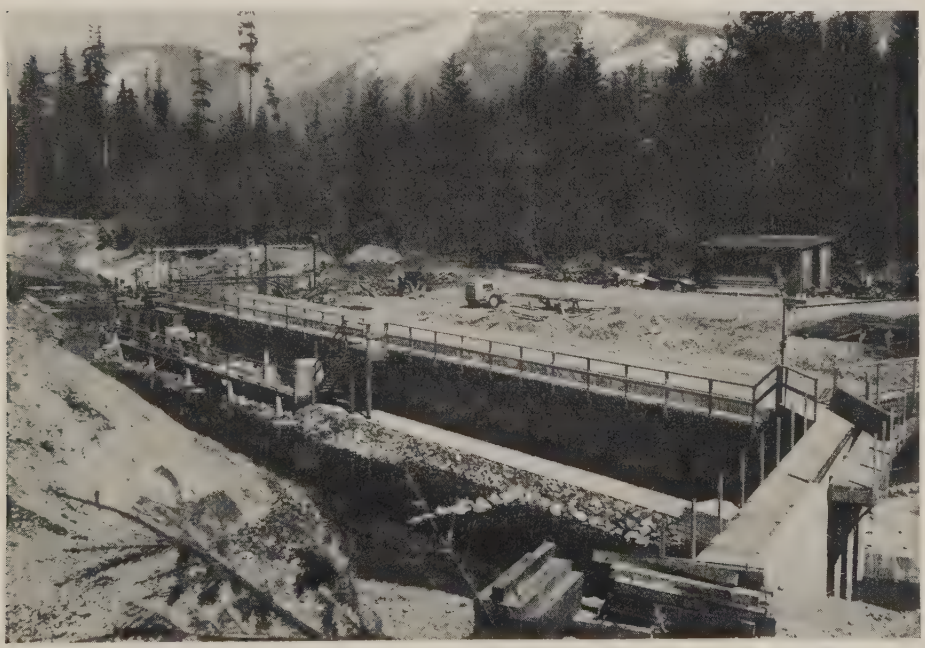

FIGURE 15.—*Looking downstream at the Robertson Creek Experimental Test Flume being prepared for 1960 louver studies.*

The flume will be used by the Fish Culture Development Branch for the study and testing of canal-type downstream migrant fry and smolt guiding devices. Plans for 1960 and 1961 call for a continuation of the study of louvers begun at the Puntledge River test flume in 1957. Future work is tentatively planned on other types of screening and deflection apparatus, alternative types of bypasses, etc. Figure 15 shows a photograph of the flume as it was being prepared for the 1960 louver studies.

The Pacific Biological Station of the Fisheries Research Board of Canada plan on using the flume for the study of energy requirements of swimming adult fish. This work would also be a continuation of studies begun at the Puntledge River test flume in 1958.

Field Camp Facilities

A field camp to service the Robertson Creek Spawning Channel and Experimental Test Flume Projects will be complete by the summer of 1960. The camp consists of a living quarters and office to accommodate six men and a detached warehouse and fenced storage yard. The warehouse contains about 800 square feet of storage and work space and also has a room set aside as a small biological laboratory. The warehouse and storage yard share a two-ton travelling overhead hoist. Total cost of the camp facilities will be about $16,000.

Discussion and Summary

The immediate operational plan for the spawning channel is to introduce and build up substantial runs of pink, coho and spring salmon in Robertson Creek. As well as providing for this development programme, the channel facilities were designed with sufficient flexibility to enable the carrying out of a host of applied and fundamental studies aimed at overcoming current multiple water-use and fisheries development problems. The objectives of such studies might be as follows:

1. To assess, modify and improve fish culture techniques.

2. To investigate the conditions necessary for most efficient use of water in rearing pre-migratory young salmon.

3. To gain additional background information on the migration, spawning, incubation and rearing of Pacific salmon.

It is not in the scope of this paper to attempt to outline the possible biological and engineering studies which could be carried out to meet the above objectives, but it is obvious the list of possible studies would be long. The priority on certain applied biological studies is quite high and it is expected that work will begin on these at an early date.

The purpose of this paper has been to review salmon spawning channels which have recently been constructed and to describe the objectives and details of development of the Robertson Creek Spawning Channel. A detailed engineering description of the spawning channel and its appurtenant facilities as they stand in 1960 has been given. Where possible, design considerations and reasoning behind their adoption have been given.

The biological staff of the Fish Culture Development Branch have already begun to utilize the new spawning channel facilities. The preliminary results of the first project are reported by MacKinnon (1960) elsewhere in this issue.

Acknowledgments

The Robertson Creek spawning channel was the product of the combined efforts of several of the staff of the Fish Culture Development Branch in the Pacific Area.

Those associated directly with the project were J. P. Parkinson, project engineer on detailed design and construction, and P. Ryan on design and field supervision.

L. Edgeworth, senior engineer, was consulted because of his experience in the design of the Jones Creek channel. D. MacKinnon of the biological staff and R. E. McLaren, Chief Biologist, collaborated on the biological requirements. C. H. Clay, Chief Engineer, Pacific Area, was responsible for overall direction, and also read this report and made many helpful suggestions.

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A Successful Transplant of Salmon Eggs in the Robertson Creek Spawning Channel

by

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Abstract

A relatively large-scale eyed egg transplant of pink salmon into a newly-constructed spawning channel produced a fry output of 95% (91% of the number of eggs taken from fish). This extremely high survival is credited to near optimum conditions in the channel.

Introduction

One of the major objectives of the Robertson Creek spawning channel, described in detail by Lucas (1960) elsewhere in this issue, is to establish a population of pink salmon (*Oncorhynchus gorbuscha*) in the Somass River system. This river system, located in the Alberni area of Vancouver Island, B.C., supports well-established populations of all other species of anadromous Pacific salmon and steelhead trout (*Salmo gairdnerii gairdnerii*). The only major runs of pink salmon on the west coast of Vancouver Island occur in the northernmost part. Minor runs are present in a number of streams along the remainder of the west coast of Vancouver Island. Occasional sightings of pink salmon are reported in the lower reaches of the Somass river system in some years. This species has never been reported above the Stamp or Sproat River falls (Figure 1), where the major spawning grounds of spring salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*) and steelhead trout are located. These falls have always been partial barriers to coho, spring, sockeye and steelhead, and might have been total barriers to weaker swimming pinks. Well-designed fishways recently installed by the Department of Fisheries at these falls have made upstream passage relatively easy.

It is not known whether pink salmon were once present in large numbers in this system and for some reason have declined to negligible numbers. It may be that this river has never supported a large population of this species. It is believed, however, that if a population of pink salmon could be established in this river such that some of their numbers would distribute themselves through the upstream area of the system, it could successfully maintain itself, as have the populations of the other species in this river system. It appears to be a characteristic of this species to remain at low population levels after the numbers in one generation have been reduced below a "recovery level". The existence of barren years in pink salmon streams is a common phenomenon. One possible explanation of this is that the rigid two-year life span, unique to this species, precludes recruitment from other cycle years. It seems evident that the small numbers of pinks in the lower reaches of this river will never establish themselves in numbers large enough to fully utilize the potential of this system without the aid of fish culture measures.

The Department of Fisheries has considered the possibility of establishing pink salmon in this system for some time. The construction of the Stamp River falls fishway in 1955 and the Robertson Creek spawning channel in 1959-60 made the project appear feasible. Consequently, large-scale transplants of pink salmon eggs were planned to be made each year for at least two and possibly four consecutive years in the Robertson Creek channel. Since the subaqueous portions of the channel were to be completed and flows could be provided by late October 1959, an eyed egg transplant was possible in that year. The remainder of the construction schedule was such that the migrating fry could be counted out of the channel before flows in the channel were reduced in late April 1960.

This part of the programme has been carried out and the purpose of this paper is to report the success of the transplant to the present stage.

FIGURE 1.—*A portion of the Somass River System showing the main rivers.*

Methods

It was planned that all eggs for this transplant would be taken from the usually large pink salmon escapement to the Tsolum River near Courtenay on Vancouver Island, B.C. Collecting facilities were installed at the counting weir near the mouth of this river and egg taking operations began. However, a small escapement to the Tsolum (approximately 15 per cent of the expected) necessitated moving the egg-taking operations to the Indian River in the North Arm of Burrard Inlet near Vancouver. As a result of the failure of the Tsolum River plans and difficult conditions for taking eggs on the Indian River, approximately 1.7 million eggs were collected instead of the 3-5 million originally planned.

The eggs were stripped, fertilized, and water hardened in the conventional manner. Five-gallon tinned cylindrical cans were used for egg transport. First these cans were filled with water to overflowing, the fertilized eggs were entered to replace the water to the $\frac{3}{4}$ mark on each can, then covered with tight-fitting lids. Between September 23 and October 14, 1959, the eggs were transported to the Puntledge Hatchery[1] near Courtenay, Vancouver Island, B.C. by means of either boat and truck or aircraft and truck. The eggs were gently stirred once an hour during transportation and the water lost through stirring was replaced. In all cases the eggs were in the hatchery by the evening of the day they were removed from the fish.

At the hatchery the eggs were placed in 16″ × 24″ wire baskets and placed in water-filled troughs. The inflow taps and outflow pipes were regulated so that six gallons of water per minute were flowing to cover the eggs with two inches of water. Eash basket held approximately 24,000 eggs and each trough held 6 baskets. One application of eight fluid ounces of malachite green was applied to each trough each day from a stock solution prepared by dissolving one-half lb. of malachite green into five gallons of water. Dead eggs were counted and recorded throughout the operation to determine the hatchery and transportation mortalities.

Eggs were held in the hatchery until they were distinctly eyed. This took approximately eight to ten weeks at temperatures ranging between 33° F. and 51° F. The eyed eggs were then hazed and dead eggs were removed prior to packing in standard egg trays and shipping cases. A measuring container was calibrated by averaging the counts of the number of eggs in this container filled three times. The trays were then lined with cheesecloth and filled with a measured number of eggs. Each tray held an average of 4176 eggs (actual sample counts: 3993, 4215, 4320) and each shipping case held 13 trays. The loaded cases were thoroughly soaked with water and transported the 75 miles to Robertson Creek by truck.

The eggs were planted across the 35-foot width of the channel in trenches three feet apart dug to a depth of 12 to 16 inches. During planting the water flow was temporarily reduced to provide a water depth of approximately one inch. This flow was sufficient to provide an exchange of water in the planting trenches without sweeping the eggs downstream. The eggs were poured from the trays underwater into the trenches at the rate of approximately 4000 per linear yard of trench. Ten trays of eggs were placed in each trench row and carefully covered with gravel. Since the centres of the

[1]*The Puntledge River hatchery facilities were loaned to the Department of Fisheries through the courtesy of the Provincial Department of Recreation and Conservation.*

planting rows were three feet apart, the density of planting was approximately 4000 eggs per square yard. The eggs were planted in three lots to insure that they were well eyed before planting. The following planting schedule was followed:

Nov. 18th, 1959	298,718 eyed eggs
Nov. 27th, "	750,732 " "
Dec. 3rd, "	592,206 " "
Total	1,641,656 eyed eggs

Of this total, 376,530 eggs were collected at the Tsolum River and the remainder were taken at the Indian River.

During the planting each of four baskets (10 meshes to the inch of wire screening) measuring 5" × 5" was filled with channel gravel containing 200 eggs. These were sealed and planted in representative sections of the channel. In addition, one large basket measuring 12" × 12" × 18" was filled with gravel containing 1000 eggs. This basket was planted in mid-stream. At the completion of planting the intake gates to the channel were set to allow an inflow of approximately 20 c.f.s. This flow was the maximum permissible in the channel at the existing stage of construction and it provided a water depth of six to eight inches with a surface velocity of one to 1.3 ft./sec.

One of the basket plants was removed January 21, another on February 6, and a third on February 19, 1960. The remaining small basket and the large basket were removed on April 22 at the completion of the fry migration. These egg samples were examined for survival and the progress of incubation. Additional checks were made by digging into the planting rows on February 6 and on March 1.

Surveys of the river system were made in September, 1959. Attention was paid to the portion of the lower river where occasional sightings of adult pink salmon had been made in previous years. Attention was also paid to certain points in the river where pink salmon, if present, would be observed. Since adult pink salmon were not seen at these points in 1959 it is felt that evidence of this species anywhere in the system in 1961 may be considered a result of the transplant.

On March 15 a Wolfe-type fry trap was installed approximately 1000 ft. downstream of the planting area. All fry were trapped as they migrated out of the area. These fry were counted during the early part of the migration and estimated by weighing when the runs increased. All fish that were not counted were weighed in 210-gram lots and released. Periodically throughout the night's run one of the 210-gram samples was counted. The average of these samples counted during the night was multiplied by the number of weighings for that night to provide an estimate of the total night's migration.

Results

The mortality of eggs from the time they were collected until they were eyed in the hatchery totalled 3.9 per cent. An additional 0.2 per cent mortality was recorded during packing and transporting to the planting site.

Sampling of the planted area on February 6 and March 1 failed to reveal any dead eggs or alevins. Several live alevins were observed in each of these separate samples.

The following analysis of the basket plants provides a good indication of the survival rate, the time of hatching, and the stage at which losses occurred.

Jan. 21, 1960	live eggs	119
	live alevins	62
	dead eggs	16
	dead alevins	3
	Total	200
Feb. 6, 1960	live eggs	0
	live alevins	185
	dead eggs	9
	dead alevins	6
	Total	200
Feb. 19, 1960	live eggs	0
	live alevins	186
	dead eggs	11
	dead alevins	3
	Total	200

Table I

Estimations of the Nightly Emigration of Pink Fry from Robertson Creek Channel, 1960.

Date	Total No. of Weighings	No. of Samples Counted[1]	Average No. Fry Per Sample	Range	Estimated Nightly Migration
Mar. 15–28	—	—	—	—	541
Mar. 28–Apr. 4	—	—	—	—	44,751
Apr. 4–5	81	9	700	676–731	61,584
5–6	89	9	697	663–750	68,176
6–7	140	5	731	700–772	105,761
7–8	154	8	775	743–828	124,030
8–9	100	8	756	706–783	81,740
9–10	113	7	775	739–819	93,472
10–11	243	9	755	719–800	183,462
11–12	200	8	767	705–803	153,695
12–13	271	7	777	746–817	210,567
13–14	244	8	784	746–836	192,710
14–15	118	7	784	724–833	93,790
15–16	106	6	775	752–798	77,550
16–17	48	5	705	668–753	30,340
17–18	20	3	720	681–746	12,280
18–19[2]	—	—	—	—	11,138
19–20	—	—	—	—	9,996
20–21	—	—	—	—	2,251
21–22	—	—	—	—	1,135
Total	1927	99	10,501	9967–11,069	1,558,969
Average	138	7	750	712–791	

[1] *The actual counts of samples were added to night's estimates.*

[2] *The trap was removed for construction purposes. The night's migration was estimated by interpolation.*

Examination of the contents of the baskets removed at the completion of the run showed that the majority of the live fry had escaped. The smaller basket contained four dead eggs, one dead fry and 52 live fry and the larger basket contained 15 dead eggs, one dead fry and 58 live fry.

The first fry was trapped March 15, but significant numbers did not migrate until March 28. The size of the nightly migrations remained at a relatively low level for the following week. Virtually all of the fry moved out of the channel during the 13-day period between April 4 and April 16. Table 1 gives the nightly estimates of fry output along with the sampling information used in the calculation of these estimates. The total output of 1,558,969 fry represents a survival of approximately 95 per cent from the eyed egg stage to migrating fry. When hatchery and shipping losses are considered the total survival from eggs stripped from the adult fish to migrating fry is approximately 91 per cent.

Discussion

Survival from egg to fry recorded from naturally spawning pink salmon in British Columbia streams has varied from about one per cent to 23 per cent. It is generally accepted that the pink fry output from an average stream is approximately 10 per cent. The survival from both eggs deposited by naturally-spawning fish and transplanted eggs in the controlled spawning channel at Jones Creek was 37 per cent. (Hourston and MacKinnon, 1956), (Neave and Wickett, 1955).

The exceptionally high survival of the Robertson Creek transplant leads to the conclusion that conditions in the channel were very close to optimum for survival of eggs, alevins and emerging fry. Additional evidence of good conditions for survival is suggested by the fact that a number of abnormal fry were recorded during the trapping and sampling of the migration. Fry with grossly deformed bodies, Siamese twins, and albinos survived and emigrated from the spawning area. In natural streams the morphologically deformed fry generally do not survive emergence from the compacted gravel and the albinos are believed to be readily taken by predators.

The most obvious conditions that can be credited with the high survival in this channel are porosity and controlled flow. Good porosity is essential to supply oxygen to and remove waste products from the developing eggs and alevins. Mortality from physical damage and suffocation during emergence is also reduced in loose clean gravel. Controlled flow precludes mortality from scouring and insulates developing eggs and alevins from some of the deleterious effects of the winter environment. While it is logical to credit the high survival to these factors it is possible that more obscure factors may also have contributed. It is probable that this newly-constructed channel is relatively free of disease-producing bacteria and fungi as well as vertebrate and invertebrate predators of eggs and fry. An interesting thesis in this respect is that if these organisms depend upon dead and decaying eggs and fry to become established in a stream, the high survival of egg to fry recorded here, may never allow these organisms to increase to a level sufficient to cause significant mortalities.

Comparison of this channel and the channel at Jones Creek allows assessment of the reasons for the increment of survival at Robertson Creek that was greater than the 37 per cent recorded at Jones Creek. The most important difference is believed to

be the larger gravel in the Robertson Creek channel. The gravel in Robertson Creek ranges in size from three-quarters of an inch to four inches in diameter, while that of Jones Creek ranges in size from one-quarter to one and one-half inches. Another important difference is the clearer water entering the Robertson Creek channel. Water is supplied to this channel at a dammed outlet of a lake. Water entering the Jones Creek channel passes through a valley characterized by clay banks. Much of the silt carried in this water is deposited on the channel streambed. A third feature that could explain higher survivals in Robertson Creek is the moderate winter conditions. The Jones Creek channel generally freezes over in the winter and ice forms at the baffles located every 100 feet in the channel. Besides altering the hydraulics of the channel this ice can scour alevins out of the gravel during spring breakup. These three differences are believed to provide the best explanation of the differences in survival. Most other features affecting survival are common to both channels.

The immediate significance of the excellent results of this transplant is that the chances of success in establishing a population of pink salmon in the Somass River system have increased. There are, however, still many factors governing the survival from fry to the return of adults, and a transplant of this size even with good survival in future stages can only be expected to provide the nucleus for an established pink run of commercial value.

These results have added significance in the field of fish culture methods. The density of planted eggs was at least twice that possible by naturally-spawning fish. To duplicate this deposition of eggs approximately 2000 pink salmon would have to spawn in a little more than 400 square yards of stream. If this were physically possible it is probable that production would be greatly lowered.

At present the most widely practised substitute for natural spawning is hatchery propagation. Most authorities agree that hatchery-raised fry are considerably less viable in nature than naturally-produced fry. However, one of the better attributes of hatcheries is that they generally achieve high survival of fry. If future survivals in this channel continue to be as high as that of hatcheries, and if the fry from the controlled channel prove to be more viable in nature than those produced in present day hatcheries, then this method of propagation might be considered as an alternative to hatcheries in some situations.

Acknowledgments

The field supervision of this project was shared by Biologists F. C. Boyd, I. S. Todd and W. J. Schouwenburg. R. E. McLaren, Chief Biologist, Pacific Area, Fish Culture Development Branch, aided in the planning of the project and the editing of the paper.

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A Field Experiment to Determine the Effect upon Coho Salmon Fry (*Oncorhynchus kisutch*) from Spraying Sawlogs with an Emulsified Mixture of Benzene Hexachloride

by

K. J. Jackson

Department of Fisheries of Canada, Vancouver, B.C.

Introduction

Field experiments designed to determine the toxic effects on salmon fry resulting from aerial applications of emulsified benzene hexachloride sprays, to control infestation of log booms by Ambrosia beetle, were carried out in June, 1958. Assistance in carrying out this programme was received from personnel of the Fish and Game Branch, British Columbia Department of Recreation and Conservation, and MacMillan and Bloedel Company Limited. Bioassays on chum salmon fry held in sea water solutions of benzene hexachloride were also carried out by Fisheries Research Board of Canada personnel of the Pacific Biological Station.

Log booms in Alberni Inlet, in salt water, and at Sproat Lake, in fresh water, served as sites for the field experiments, Figure 1. Stormy weather immediately preceding spraying in Alberni Inlet destroyed experimental equipment and forced the abandonment of the field experiment at the salt water location. The experiment at Sproat Lake was successfully concluded and is reported below.

Method

Eight shallow floating liveboxes, each containing 15 coho salmon fry were placed in one section of an eight section boom of sawlogs. The liveboxes were made of two 18″ × 24″ pieces of $\frac{3}{8}$″ plywood joined together along the long edge in the shape of a V. The ends were screened with fly screen as shown in Figure 2. To provide buoyancy two pieces of 4″ × 4″ cedar were attached as shown in Figures 2, 3 and 4.

In addition to the shallow liveboxes a large rectangular livebox, one foot square on top, five feet deep, and divided vertically into five compartments of one cubic foot each, was placed within the experimental section of the boom in such a manner that the top compartment was just below the water surface. The bottom compartment was weighted to make the livebox float upright. Ten coho fry were placed in each compartment.

Control specimens were held in five floating triangular liveboxes, joined together and placed in a small protected bay a safe distance from the experimental area. Each livebox contained 15 coho fry, yielding a total of 75 control specimens.

Four floating triangular boxes were moored between logs within the experimental boom, being placed at approximately equal distances from one another across the width

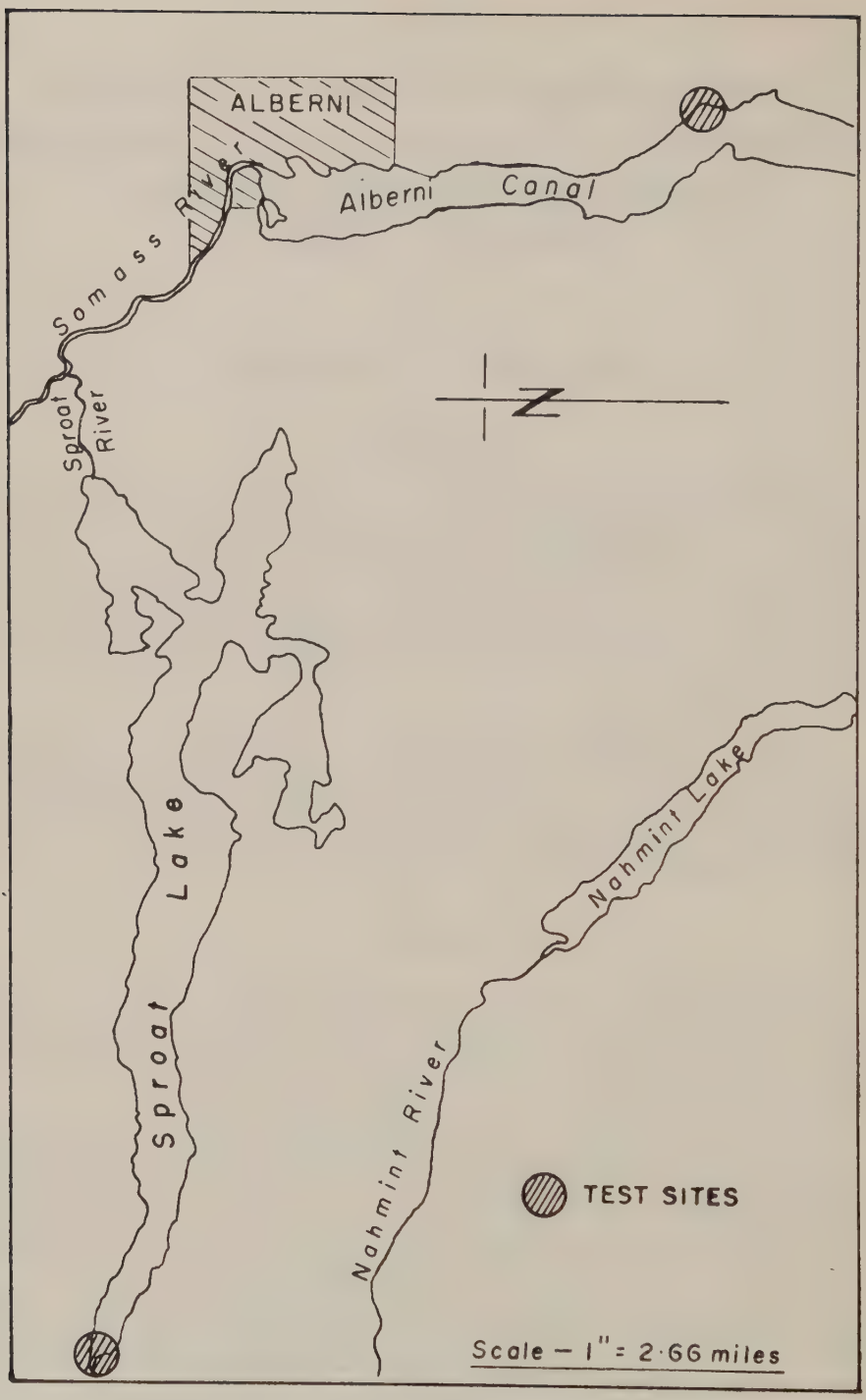

FIGURE 1.—*Map showing the location of experimental sites.*

of the area. Four floating liveboxes were moored between 2″ × 4″ members nailed to and projecting from the peripheral logs. In the results liveboxes moored within the boom are referred to as *inside* (I) and peripheral liveboxes are referred to as *outside* (0). In plan the placement of liveboxes is illustrated in Figure 5.

The aircraft approached from an easterly direction and in several passes discharged the spray material from a height of about 20 feet above the boom (Figure 6). Conditions for spraying were excellent. There was no wind and the water surface was very calm.

The liveboxes in the experimental area were examined as soon as possible after spraying had finished, and the number of fish remaining alive was noted. Water samples for quantitative analysis of benzene hexachloride content were obtained from each floating livebox at the times of the above observations. These were transferred to an insulated box containing dry ice, and taken to Port Alberni where they were frozen solid in a commercial deep freeze to prevent decomposition of benzene hexachloride prior to analysis. The samples were then transported from Port Alberni to Nanaimo in a frozen state and transferred to the Pacific Biological Station where they were re-refrigerated. The analyses were performed by Dr. M. Waldichuk of the Fisheries Research Board. The results are reported as concentrations of the gamma isomer of benzene hexachloride.

Results

The results of holding coho fry in liveboxes exposed to spray materials and the quantitative analyses for the benzene hexachloride content of water samples taken at various intervals from the liveboxes are presented in Tables I, II, III and IV.

Table I

Number of coho fry remaining alive after exposure to spray material in the shallow floating live boxes after various intervals of time.

Livebox Position	0 minutes	+ 15 minutes	+ 32 minutes	+ 105 minutes	+ 9½ hours
1–0	15	0	0	0	0
2–0	15	0	0	0	0
3–0	15	0	0	0	0
4–0	15	0	0	0	0
1–1	15	0	0	0	0
2–1	15	0	0	0	0
3–1	15	0	0	0	0
4–1	15	5	3	3	0

Table II

Number of coho fry remaining alive after exposure to spray material in the vertical livebox after various intervals of time.

Depth below surface	0 minutes	+ 120 minutes	+ 9½ hours
0′–1′	10	1	1
1′–2′	10	10	10
2′–3′	10	10	10
3′–4′	10	10	10
4′–5′	10	10	10

Table III

Number of coho fry remaining alive in the floating "control" liveboxes after various intervals of time.

0 minutes	+ 50 minutes	+ 165 minutes	+ 9¼ hours
75	75	75	75

Table IV

Results of analyses of benzene hexachloride from water samples obtained at various intervals of time from the floating triangular liveboxes.

"Inside" Liveboxes			"Outside" Liveboxes		
Livebox Number	Gamma Isomer (in ppm)	Time	Livebox Number	Gamma Isomer (in ppm)	Time
1–I	1.43	0 + 15 mins.	1–0	1.43	0 + 15 mins.
2–I	1.25	"	2–0	1.60	"
3–I	1.25	"	3–0	1.29	"
4–I	1.60	"	4–0	1.25	"
	Average—1.38 ppm.			Average—1.39 ppm.	
1–I	0.338	0 + 32 mins.	1–0	0.165	0 + 32 mins.
2–I	0.448	"	2–0	0.416	"
3–I	0.428	"	3–0	0.544	"
4–I	0.225	"	4–0	0.934	"
	Average—0.360 ppm.			Average—0.515 ppm.	
1–I	0.079	0 + 105 mins.	1–0	0.074	0 + 105 mins.
2–I	0.093	"	2–0	0.078	"
3–I	0.126	"	3–0	0.050	"
4–I	0.024	"	4–0	0.085	"
	Average—0.081 ppm.			Average—0.072 ppm.	
1–I	0.032	0 + 10 hrs.			
2–I	0.036	"	2–0	0.033	0 + 10 hrs.
	Average—0.034 ppm.			Average—0.033 ppm.	

To illustrate the nature of the decrease in benzene hexachloride concentration with respect to time, the average concentrations of benzene hexachloride obtained in the inside series of floating liveboxes were plotted against time. The resulting graph is shown in Figure 7.

After two hours the entire experimental boom was examined carefully to determine whether any fish "holding" under the boom had been affected. No living or dead fish were noted. On previous occasions small numbers (two to four) fry had been seen under the booms at a depth of about four feet.

Discussion

All control specimens remained alive, and after 9½ hours all experimental specimens in the floating liveboxes had died. The method of presentation of the results would appear to indicate that all of the fish in the floating triangular liveboxes except 4-1 had died in 15 minutes. It took fifteen minutes, however, to complete the circuit of the liveboxes, to obtain water samples and to record observations. It is likely therefore that the mortality of the coho fry took place in less than 15 minutes. The fish in the first floating livebox examined (1-0) were either dead or had lost their equilibrium when first examined three to four minutes after spraying had finished. At this time water within and surrounding the liveboxes was noticeably "milky". This water condition was judged to have persisted for less than 15 minutes.

It is noted that the survival of fry in the rectangular vertical livebox was very different from those held in the shallow triangular liveboxes. All but one fish held in the top (0-1 ft.) compartment died. All fish in the lower compartments survived, suggesting that a density differential or dilution prevented toxic concentrations of spray materials from reaching fish held at depths of more than one foot below the surface.

The results of the water sampling shown graphically in Figure 7 show that the dilution trend was curvilinear; that a very rapid dilution took place at first and that small concentrations of benzene hexachloride remained in the water surrounding the boom for as much as 10 hours.

The gamma isomer of benzene hexachloride is quoted to be toxic to fish at concentrations as low as 0.05 ppm. and trout fingerlings were disabled by concentrations as low as 1 ppm.[1] On the basis of bioassays carried out with chum salmon fry held in salt water solutions of benzene hexachloride, the suggested "safe" level of mixed isomers was 0.01 to 0.025 ppm.[2] Table IV shows the average concentration of benzene hexachloride (gamma isomer) as much as fifteen minutes after spraying had ended was 1.38 to 1.39 ppm., which is greatly in excess of the cited "safe" level and also exceeds the concentrations cited to be toxic to trout.

Mr. H. Richmond, entomologist with MacMillan and Bloedel, stated that the quantity of gamma isomer applied in this experiment was 12.3 lbs. over eight sections, or 12.3 lbs. per 34,848 square feet. It has been noted that only the coho fry held in the top compartment of the vertical livebox died. The remainder lived. For the purpose of obtaining an approximation of the initial dosage of benzene hexachloride, it was assumed that the spray material was confined to a hypothetical layer of water extending to one foot below the surface. A calculation establishes that the *average* concentration of benzene hexachloride in the hypothetical surface layer would initially have been

$$\frac{12.3}{34{,}848 \times 62.4} \times 10^6 = 5.6 \text{ ppm.}$$

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[1]*Water Quality Criteria. State Water Pollution Control Bd., California, 1952.*

[2]*Resistance of Chum Salmon Underyearlings to Hexachlorocyclohexane in Sea Water. Alderdice, D. F., Fisheries Research Bd. (Unpub.)*

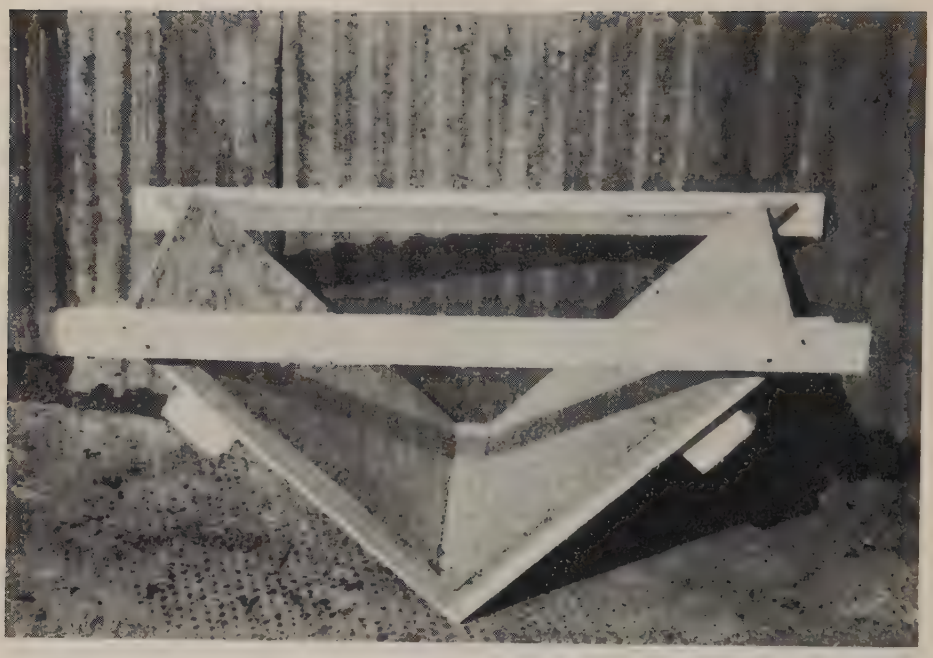

FIGURE 2.—*A typical floating triangular livebox.*

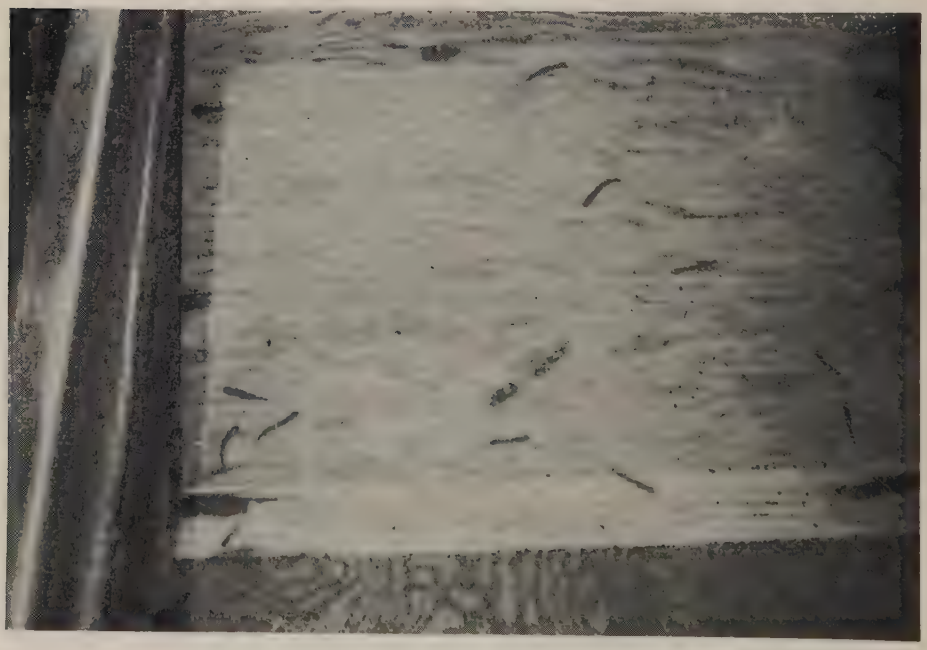

FIGURE 3.—*Coho fry held in a floating triangular livebox.*

FIGURE 4.—*Floating triangular liveboxes on the periphery of the log boom in Sproat Lake.*

FIGURE 6.—*Aircraft applying spray on the experimental boom in Sproat Lake.*

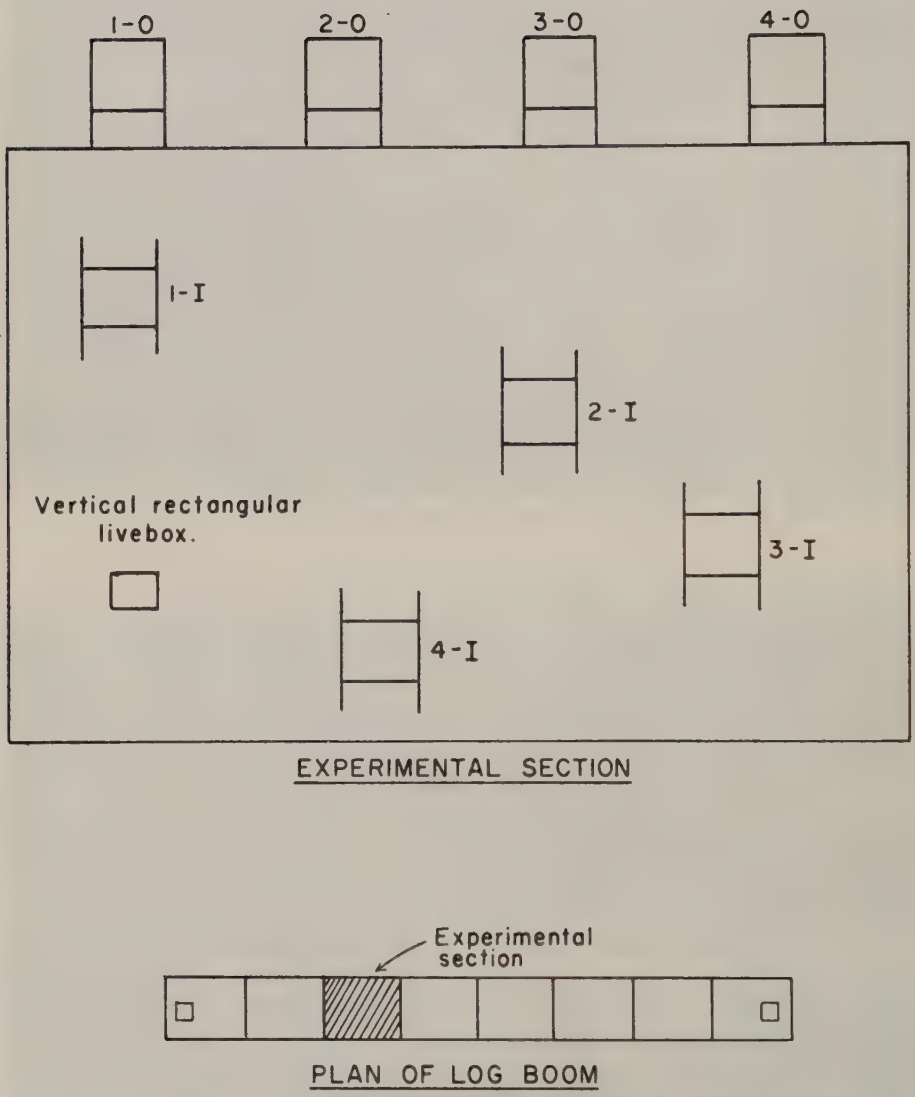

FIGURE 5.—*Diagram showing the placement of triangular floating liveboxes within the boom at Sproat Lake.*

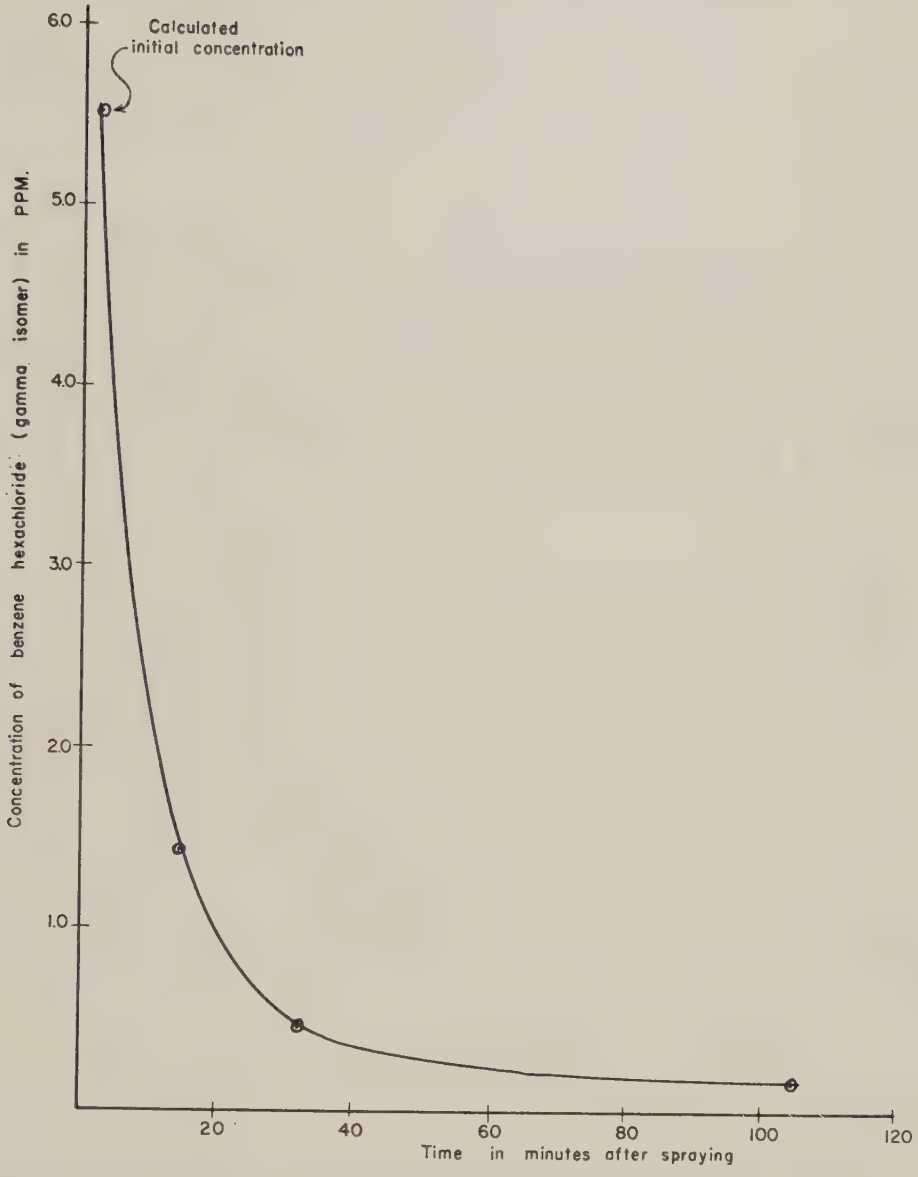

FIGURE 7.—*Curve showing the rate of decrease in the concentration of benzene hexachloride (gamma isomer) following spraying of log booms in Sproat Lake.*

Conclusions

The results of the experiment have shown that applications of emulsified benzene hexachloride at the concentrations cited (12.3 lbs. of gamma isomer per 34,848 square feet) are lethal to coho fry held within 1 ft. of the surface. Fifteen minutes after spraying had ceased the average concentration of benzene hexachloride was still in excess (1.38 ppm) of the 1 ppm, cited as toxic to trout. The decrease in concentration of benzene hexachloride was shown to be exponential, and a calculation of initial concentration based upon the amount of gamma isomer applied indicates that it exceeded 1.38 ppm by a factor of three or four.

The results obtained from holding fish in a vertical gradient show that fish held at depths of more than 1 ft. were not killed.

The results obtained from holding fish in a vertical livebox showed that fish were not killed at depths of more than 1 ft. below the surface indicating that lethal concentrations of spray may be largely confined to the surface.

The livebox method was well suited to this type of experiment. Both the shallow and vertical liveboxes held fish satisfactorily for the duration of the experiment and the results indicated that the mortality from spraying followed a regular pattern.

The Fish Facilities at the Whitehorse Rapids Power Development, Yukon Territory

by

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Department of Fisheries of Canada, Vancouver, B.C.

Introduction

In the spring of 1957, the Northern Canada Power Commission initiated construction of a power development on the Yukon River at Whitehorse Rapids, approximately two miles south of Whitehorse, Yukon Territory. This development, which was designed to supply hydro-electric power to the Whitehorse area, required that a dam be constructed across the river.

The Yukon River in the vicinity of Whitehorse supports valuable stocks of lake trout, grayling and least cisco. It further serves as the migration route for a population of spring salmon which spawns in the upper watershed area, primarily in the M'Clintock River system, tributary to Marsh Lake (Figure 1).

Initial studies of the possible fisheries problems posed by the power development indicated that unless suitable fish facilities were provided to permit free access upstream the important populations of spring salmon and resident species would be seriously affected. Following a series of meetings attended by representatives of the Department of Fisheries and the Northern Canada Power Commission, agreement was reached to provide permanent fish facilities at the dam.

The facilities were designed to pass upstream migrants around the obstruction, but their installation was necessarily deferred pending completion of the power dam. By 1958, construction of the dam had progressed to the point where the structure constituted a complete obstruction to all upstream migration and temporary facilities were installed for operation during the summer of that year.

The permanent fish facilities came into service on June 26, 1959, and during the succeeding months an assessment programme was conducted to determine their efficiency.

Description of the Whitehorse Rapids Power Development

Local conditions at the Whitehorse Rapids power site are such that the most economic damsite is situated upstream from the rapids proper; but if the powerhouse were constructed integrally with, or adjacent to the dam, as is customary at most mainstem developments, the 15-foot fall between the damsite and the base of the Rapids, representing nearly 25 per cent of the contemplated gross head on the plant, would not be harnessed by the proposed development. This undesirable feature of the site was overcome by locating the powerhouse near the base of the rapids and conducting water to it from the forebay of the dam, approximately 2000 feet upstream, by means of a canal.

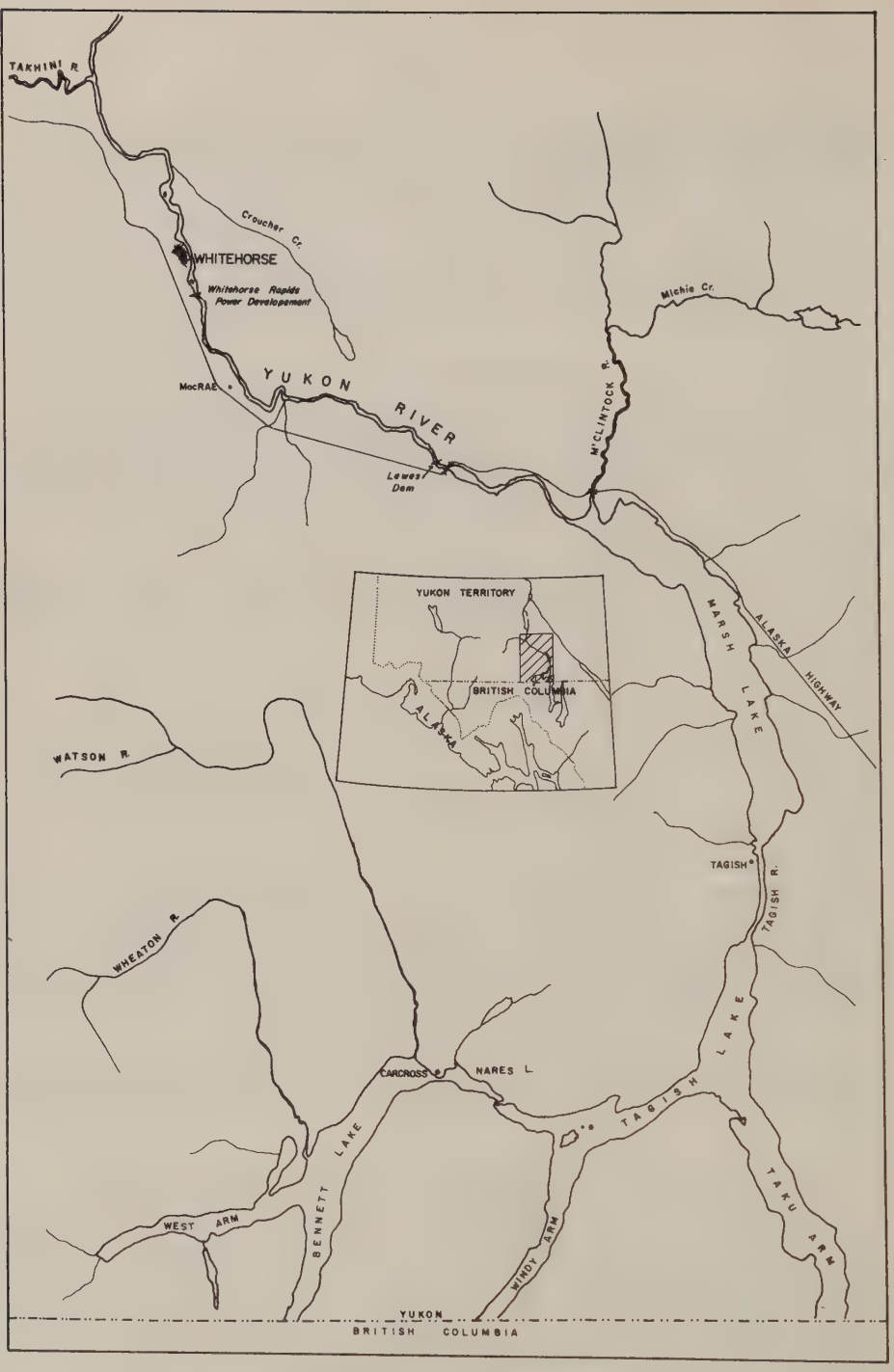


FIGURE 1.—*Map of the Upper Yukon River Watershed.*

Thus, while the project is essentially of the main-stem type, it presents as well, certain of the characteristics of a diversionary scheme.

Construction of the Whitehorse Rapids power development, the salient features of which are described below, was initiated in the spring of 1957 and the plant came into service in November, 1958 (Figure 2).

(a) Spillway Dam

The spillway dam is situated approximately 1200 feet upstream from the head of Whitehorse Rapids on the Yukon River, two miles south of the city of Whitehorse. It consists of an impervious-core earth-fill non-overflow section with an integral concrete spillway consisting of two 40-foot wide undershot spillway gates and a 10-foot wide regulating gate on the crest of an ogee overflow section. A concrete apron and training walls extend from the toe of the ogee nearly 200 feet downstream where the apron terminates in a flip bucket which directs the spillway discharge into the atmosphere and away from the structure in order to forestall any future problems arising from erosion of the river bed in the immediate vicinity of the dam.

The spillway dam raises the normal river level at the site by approximately 47 feet, and the impoundment so created extends upstream for nearly 20 miles to the Lewes Dam at the outlet of Marsh Lake.

(b) Powerhouse

The Whitehorse Rapids powerhouse is situated at the toe of the Rapids on the left bank nearly 2000 feet downstream from the spillway dam. It houses two 7500-hp propeller-type turbines, each of which draws 1250 c.f.s. at full load under a normal head of 62 feet. Provision has been made for future expansion, however, and the excavation for a possible third unit, adjacent to, and in line with the two existing ones, was completed under the initial contract.

Forebay fluctuations are restricted in practice to a one-foot range, so flow regulation at the site is negligible and the plant is essentially of the run-of-the-river type.

(c) Power Canal

Two impervious-core earth fills, which are approximately parallel at a distance of about 100 feet, form a trapezoidal-shaped canal on the west bank extending downstream from the forebay of the spillway dam to within 200 feet of the powerhouse, where they are terminated in a concrete intake structure by means of which they are interconnected. Plant flows are conducted from the forebay to the intake via the power canal, and since there is no significant head loss in the canal, it is, in effect, simply a downstream extension of the spillway dam impoundment.

Flows in excess of plant demands are passed through the spillway gates to the river below, and since the natural river runoff is normally greater than the plant capacity, spill is expected to occur continuously.

Description of the Whitehorse Rapids Fish Facilities

Studies to develop an efficient economic method for passing fish around the power project were inaugurated in December, 1956. At that time a preliminary assessment of the fisheries problems associated with the proposed development indicated that upstream

migrants would be delayed at the powerhouse and blocked at the spillway dam unless suitable remedial measures were implemented at the outset. No difficulties were foreseen with respect to the powerhouse, where a standard-type collection system and fishway would serve effectively, but what appeared to be insurmountable problems were expected at the spillway dam. In this connection, model studies of the spillway disclosed that the flow pattern at the toe could be expected to vary considerably with varying discharge, and that erosion of the river bed would be such that the tailwater levels and flow patterns would alter unpredictably with the passage of time. There was no assurance therefore that any known type of fish-passing device could be adapted economically to operate effectively under these adverse conditions.

An investigation of several possible alternatives indicated that the most promising method would involve the construction of a fish barrier across the river some distance downstream from the spillway dam, where upstream migrants could be more easily attracted into the facilities. Subsequent detailed studies confirmed this and the design of suitable fish facilities proceeded accordingly. These facilities, as constructed, are described briefly hereunder, (Figure 2).

Powerhouse Fish Facilities

A collection chamber in the form of an eight-foot wide timber flume, resting on the draft tube deck, extends the entire length of the downstream face of the powerhouse, and is linked with the tailrace by three six-foot wide slidegate-controlled submerged orifices spaced uniformly along its length (Figures 3 and 4).

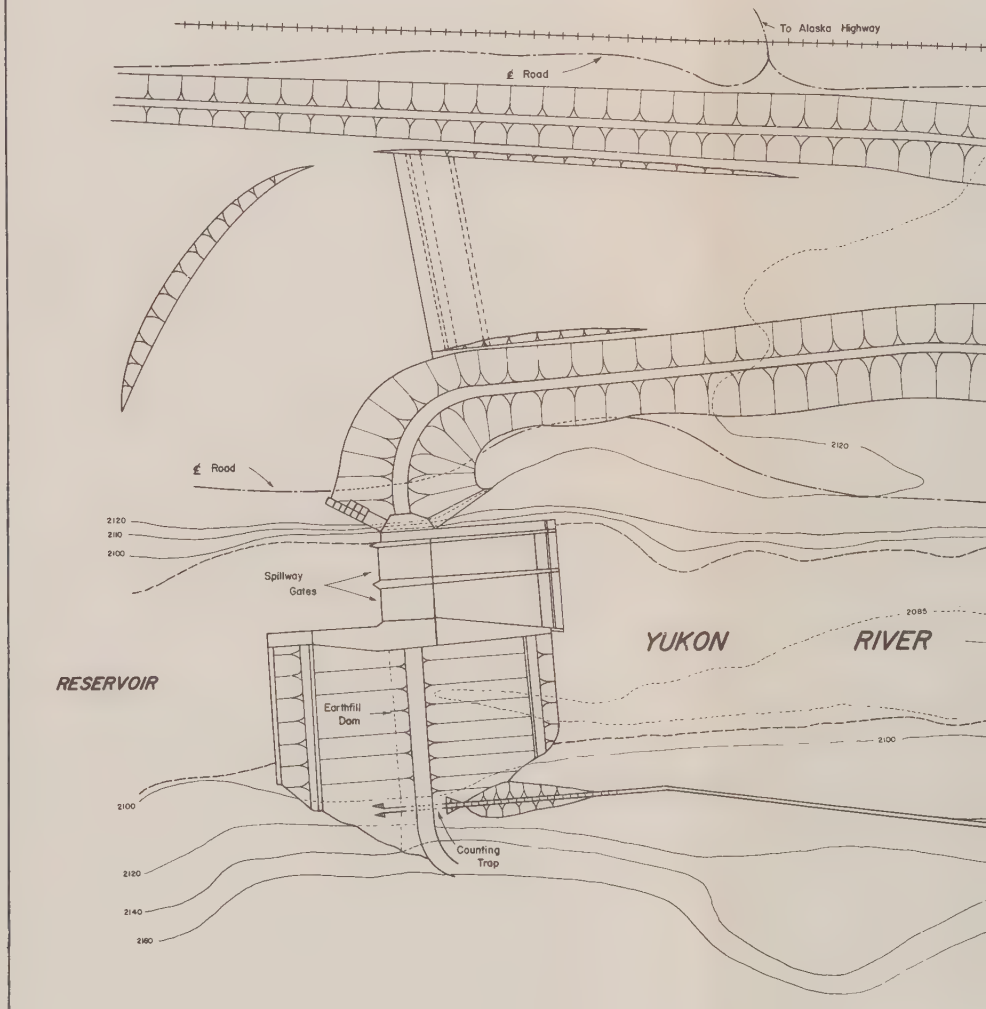
Water is supplied to the collection chamber by means of a trapezoidal-shaped rock-cut (transportation channel) which interconnects with the river near the head of the rapids, several hundred feet upstream from the tailrace (Figure 5). The channel has a minimum width of six feet and the gradient of its floor is such that it provides at least a four-foot depth of flow at all stages.

Velocities in the transportation channel and collection chamber are regulated automatically by a reinforced-concrete control structure consisting of three modified vertical slot type baffles, which provide for average velocities of 1.5–2.5 feet per second throughout the normal range of discharges. Velocity and discharge can be regulated manually as well by manipulation of the slidegates which control the discharge from the entrance ports of the collection chamber.

The facilities are so designed that the water level of the collection chamber is maintained at approximately six inches above that of the tailrace, so attraction velocities are normally in the order of 5–6 feet per second. Maximum head loss through each baffle of the control structure is restricted by design to one foot.

In operation, fish which are attracted into the tailrace locate the entrance ports, enter the collection chamber, and ascend the transportation channel back to the river where they rejoin those that had proceeded up the river directly. All migrants are therefore expected to ascend freely to the head of the rapids so it was necessary to provide only a single set of facilities to convey them from there to the forebay.

FIGURE 2.—*Plan of the Whitehorse Rapids Power Development and Fish Facilities.*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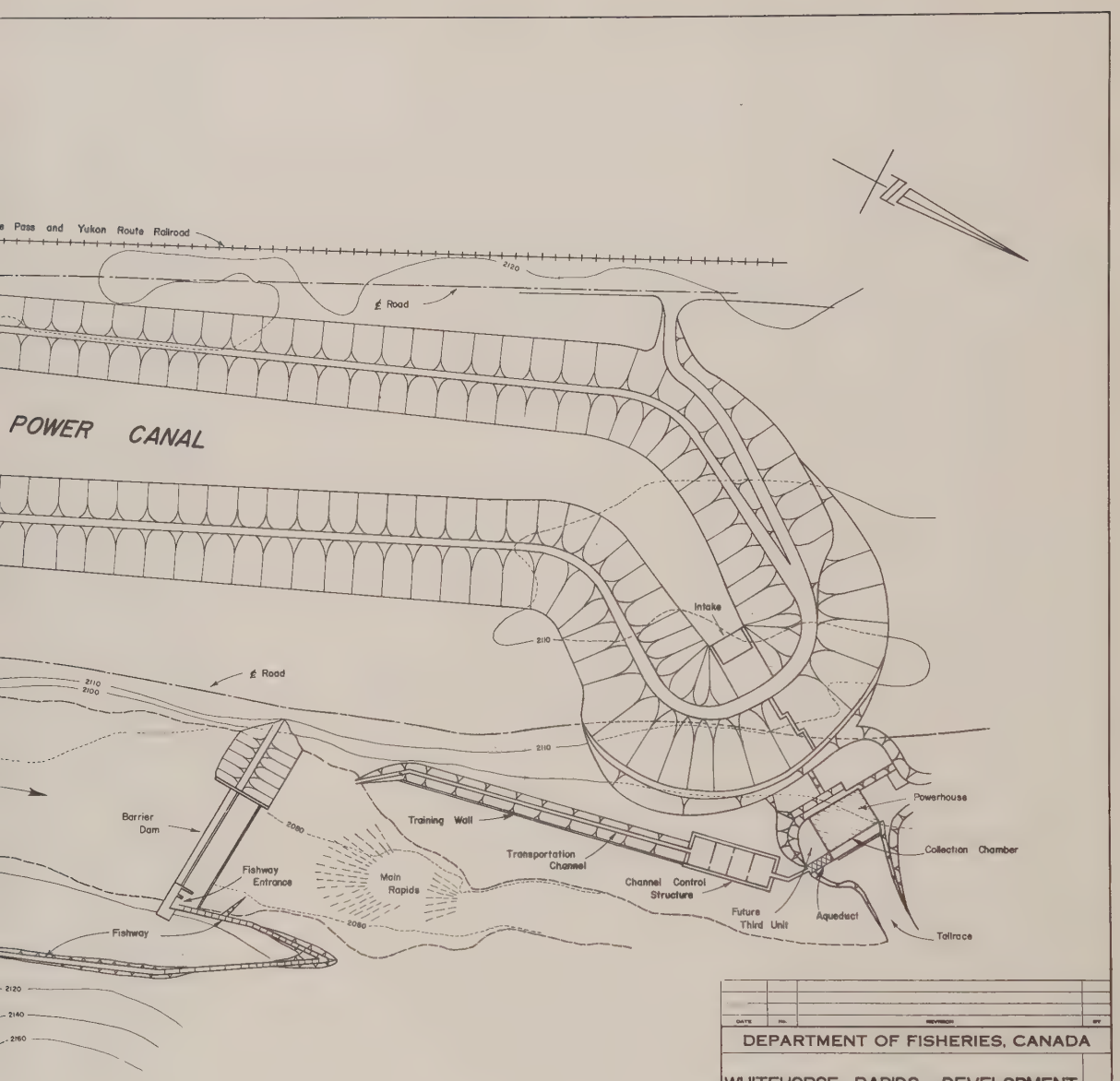

SCALE

80 60 40 20 0 40 80 120 Feet

DEPARTMENT OF FISHERIES, CANADA

WHITEHORSE RAPIDS DEVELOPMENT
YUKON RIVER
FISH FACILITIES
GENERAL LAYOUT

25-6-G2

DATE: MARCH 25 1960 | DRAWN: Hans J. Schroder | SCALED

DESIGN: | CHECK: K.M.G.

APPROVED: K.M. Gordon, ENGINEER; Vidal LeCoq, CHIEF ENGINEER

DWG. NO. 25-6-G2

FIGURE 3.—*Powerhouse and Tailrace.*

FIGURE 4.—*Lower end of transportation channel showing aqueduct leading to powerhouse collection system and tailrace.*

Spillway Dam Fish Facilities

A reinforced concrete barrier dam with a crest length of 155 feet spans the Yukon River approximately 100 feet upstream from the head of the Rapids (Figure 6). It creates a minimum water surface drop of 10 feet, and this, in combination with the hydraulic characteristics of the overfall, forms a total obstruction to migrating fish. Furthermore, the alignment of the barrier dam is angled upstream from the west bank to the east so that fish will lead naturally to the fishway entrance which is located in the east abutment of the barrier dam.

FIGURE 5.—*Downstream view from the left abutment of the barrier dam showing Whitehorse Rapids and the upper leg of the transportation channel.*

The fishway entrance pool is simply a 10-foot by 13-foot recess in the downstream face of the abutment, and upstream migrants gain entry by means of either a 12-inch by 18-inch submerged port or over a six-foot wide manually-operated telescopic weir which is submerged at all stages (Figure 7).

A weir-type fishway, six feet wide, six feet deep, approximately 1200 feet long, and having a vertical rise of 55 feet, conducts migrants from the entrance pool to the forebay of the spillway dam (Figure 8). Its lowermost leg, which is subject to submergence at high river discharges, is constructed of reinforced concrete, as is the culvert section which passes through the spillway dam, but the remainder is of creosoted timber. The fishway has a level centre section nearly 700 feet long and two end sections totalling more than 500 feet in length, each of which has been constructed on a 1:10 floor slope. These sloping sections are fitted with four-foot high weirs spaced at 10-foot intervals, and each has a 12-inch by 18-inch submerged orifice which is located at the bottom corner. These orifices are staggered from side to side at adjacent weirs.

FIGURE 6.—*Barrier dam and fishway.*

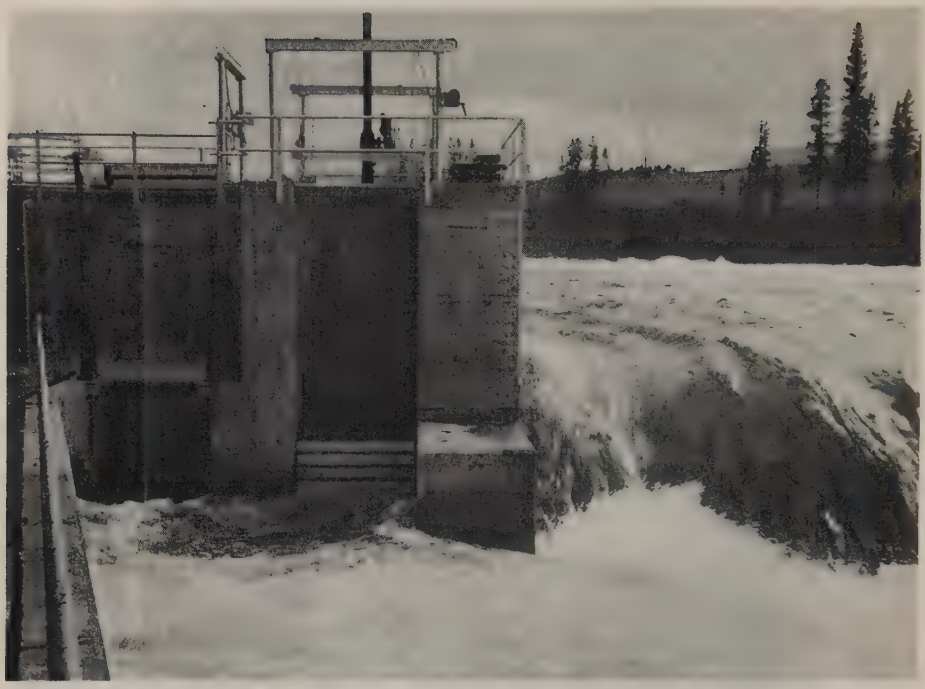

FIGURE 7.—*Fishway entrance as seen from fishway showing telescopic weir entrance at left and stoplogged auxiliary water supply sluiceway at right.*

FIGURE 8.—*Level centre section of fishway with counting trap and culvert through spillway dam in distance.*

Water is drawn into the fishway from the forebay of the spillway dam and regulation is effected by manipulation of stoplogs at the fishway exit. The structure is designed to operate with flow depths of from eight to eleven inches over the weirs, so total discharge, including that of the submerged ports, is normally in the order of 25 c.f.s. While this flow is considered to be adequate for transportation within the fishway there was some doubt that it would be sufficient to attract fish into the entrance pool without undue delay. An auxiliary water supply system was therefore provided at the fishway entrance (Figure 9). It consists of a six-foot square slidegate-controlled sluiceway through the east abutment of the barrier dam between the fishway entrance and the overfall. Flows are drawn directly from the pond behind the barrier dam and the works are so designed that this auxiliary flow can be employed either as a direct jet to attract fish into the vicinity of the fishway entrance, or it can be discharged directly into the entrance pool to augment the flow passing over the telescopic weir. The motor-operated control gate is capable of supplying in excess of 600 c.f.s. at all river stages, but its full capacity will probably not be required in practice.

Downstream Fish Facilities

Experience at similar installations suggests that losses at the spillway during downstream migrations will be slight and that those through the propeller-type turbines will also be small. Field tests to be undertaken in future, however, will determine exactly what losses are occurring. If the tests disclose that serious mortality is occurring, consideration will be given to the desirability of installing screens, louvers, or equivalent diverters, and a suitable by-pass, in the power canal.

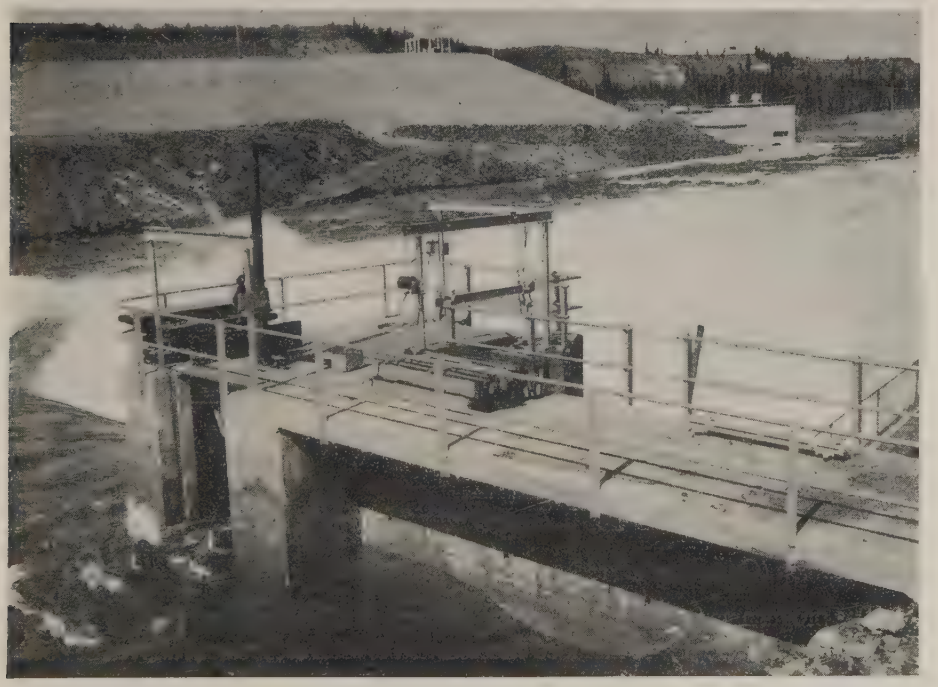

FIGURE 9.—*Upstream face of barrier dam east abutment showing auxiliary water supply intake.*

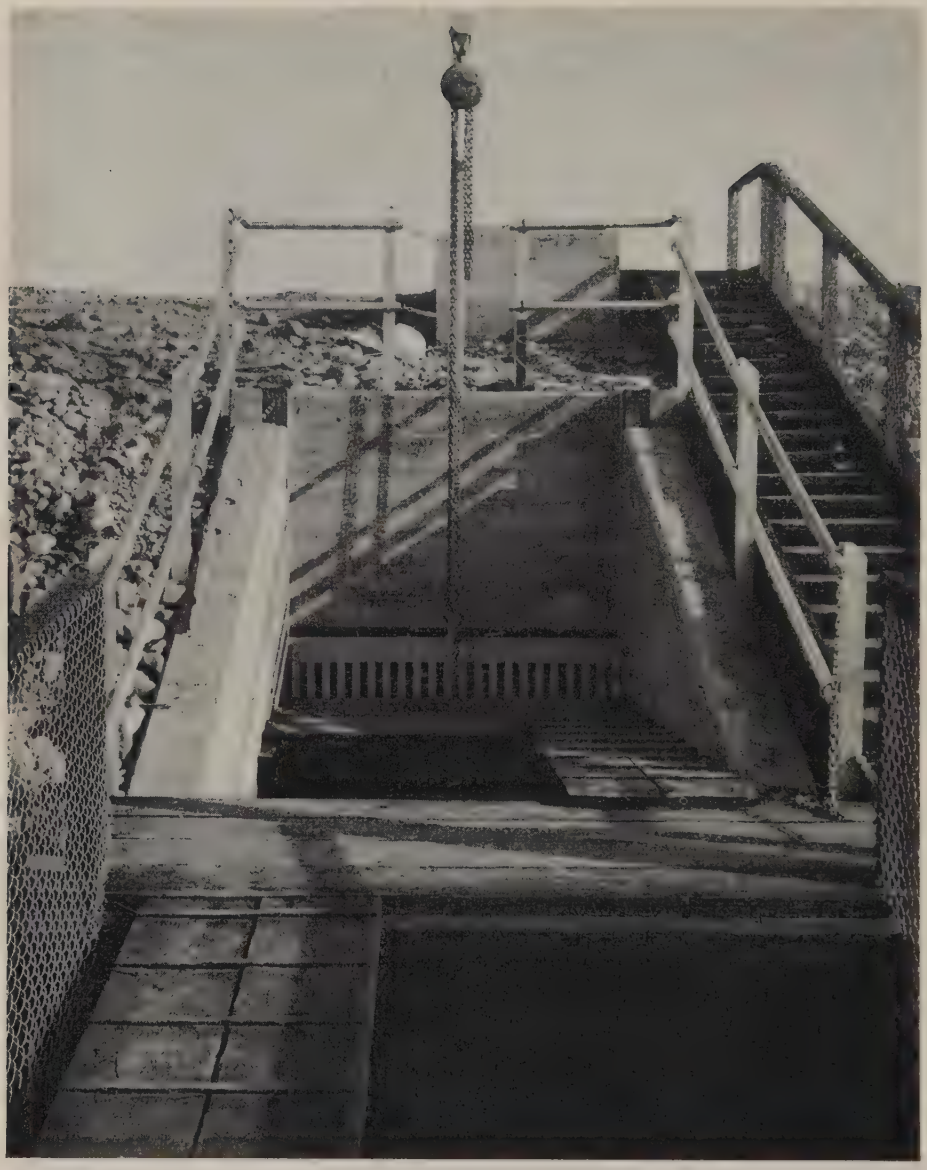

FIGURE 10.—*Vertical slot counting gate in closed position.*

The 1959 Assessment Programme

Spring Salmon (Oncorhynchus tschawytscha)

The programme for the spring salmon study at the fish facilities of the Whitehorse Rapids Power Development, included enumeration of total escapement above the power dam, tagging below the power development to measure actual delay and observation to determine general behaviour of salmon at the facilities.

A total escapement figure was obtained by the operation of a vertical slot counting gate near the fishway exit (Figure 10). The fish were released periodically during the day to avoid delay and consequent accumulation of fish.

The first salmon was sighted by Departmental personnel at the fishway entrance on July 28. Between July 29 and September 24, at which time the programme was terminated, the count at the fishway totalled 1054. Cumulative and daily migration curves are shown in Figure 11.

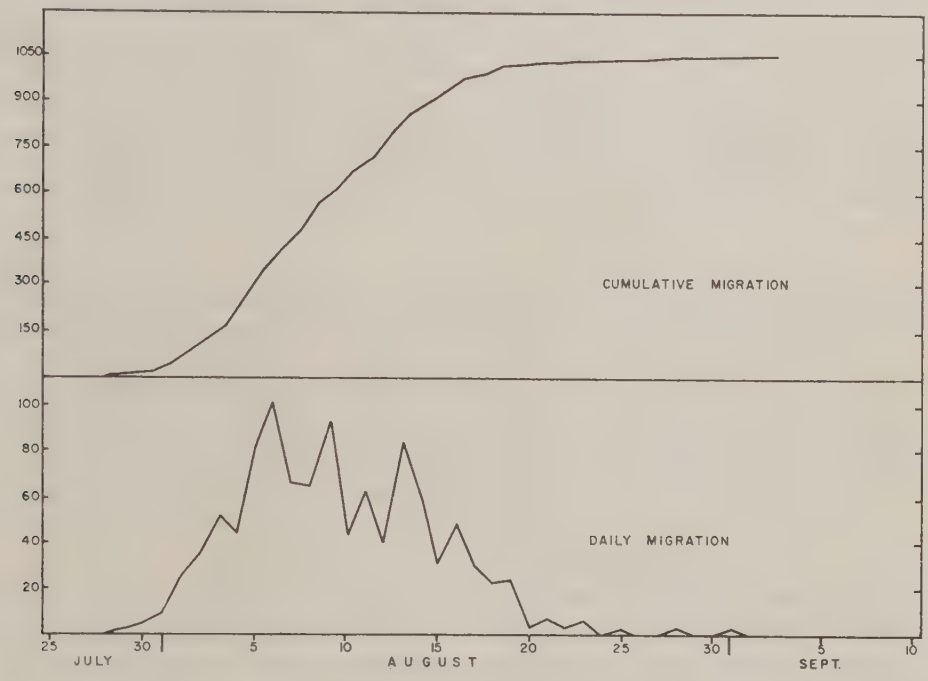

FIGURE 11.—*The Cumulative and Daily Migration of Spring Salmon ascending the Whitehorse Rapids Fishway—1959.*

Attempts to tag were unsuccessful and no reliable measure of overall delay was obtained. Of five salmon tagged on the east bank below the fishway entrance, one entered and negotiated the fishway in 28.5 hours and another in 64 hours. The remaining three were not recovered in the facilities.

Although an accurate direct measure of delay was not obtained there are other indications that the facilities operated satisfactorily. There was no delay to migration apparent on the right bank and although as many as 100 salmon accumulated in a back-eddy on the left bank below the barrier dam, delay to individual fish was probably slight. Salmon migrating on the west bank of the river would have passed through this eddy, which formed a natural resting pool, prior to finding the fishway entrance on the opposite shore. In the extremely rough water conditions prevalent in that section of river, there would be a natural tendency for salmon to accumulate in such an area.

Attraction of salmon into the fishway, as indicated by a lack of any significant accumulation in the area immediately downstream, was very good. Movement through

the relatively long structure was made without noticeable delay, although salmon demonstrated some reluctance to pass through a shaded culvert section which leads from the counting pen to the reservoir.

While a number of salmon attempted to surmount the barrier dam, none was seen in the area between it and the spillway dam. On this basis, the conclusion is drawn that the structure provided a total obstruction and thereby fulfilled the functional requirement.

There were no problems noted at the powerhouse bypass facilities. An occasional salmon was observed at the exit from the transportation channel but none was seen in the channel proper or in the tailrace. The evidence suggests that these facilities either operated very efficiently during 1959 or few if any salmon were attracted into the tailrace. During the summer of 1959 however, the turbines of the plant were discharging only a few hundred c.f.s. as compared with their full capacity of 2500. Consequently, flows issuing from the tailrace may not have been sufficient to attract salmon from the much larger flows of the river.

In terms of overall assessment, the pattern of migration as well as the general condition of the salmon indicate that the migration of this species was not seriously affected. The daily migration curve (Figure 11) does not demonstrate a skewed pattern and additionally shows that 96 per cent of the migration occurred during the 21-day period, August 1 to 20. Together these factors suggest that severe delay did not occur. Condition of the salmon was good and showed very little deterioration throughout the migration. There was also no evidence of injury noted.

An aerial reconnaissance of the area located downstream from the dam was undertaken in view of reports that small numbers of salmon had spawned in that locality in 1958 but none were noted in 1959.

Throughout the latter portion of July, an accumulation of several thousand spring salmon fingerlings, verified by scale analysis to be progeny of the 1958 escapement, were present in the non-functional number three penstock pool and small numbers were noted throughout the remainder of the programme.

Other Species

The fishway counting gate was designed to contain only spring salmon so that data on the movement of other species is based primarily on visual observation. The period of daily observation extended from July 17 to September 4.

1. *Arctic Grayling (Thymallus arcticus)*

No count was kept of the grayling passing through the fishway, however there were generally 30 to 50 individuals present in the fishway during periods of observation. Large numbers of grayling were reported utilizing the fishway for a period between June 26, when water was first introduced into the fishway, and July 17, the commencement date of this programme. The spawning period of this species is reported to be in the late spring and this population may have been on a spawning migration. Adults occurred periodically throughout the diversion channel and tailrace for the duration of the survey and during the latter part of August a number of juveniles, 3.5 to four inches in length, were observed in the transportation channel.

2. *Lake Trout (Salvelinus namaycush)*

Five lake trout were counted through the fishway and others were observed occasionally in the powerhouse collection facilities.

3. *Least Cisco (Coregonus sardinella)*

One least cisco was counted through the fishway but very few were observed in the structure even though large numbers were observed in the collection chamber and number three penstock pool throughout the summer. The migration of this species could possibly occur in the late fall or early winter.

4. *Round Whitefish (Prosopium cylindraceum)*

Round whitefish were not observed in the fishway although a small number were present in the diversion channel throughout the summer. A sample of juveniles, four to five inches in length, was taken in the lower transportation channel during the latter portion of the survey.

5. *Northern Pike (Esox lucius)*

A school of pike was sighted in the lower transportation channel on September 4 but none was seen elsewhere.

6. *Longnose Suckers (Catostomus catostomus)*

Two longnose suckers were counted through the fishway, several others were observed in the structure and schools of this species occupied the powerhouse diversion channel throughout the summer.

Spring Salmon Spawning Ground Surveys

Previous surveys had indicated that the M'Clintock system, specifically Michie Creek, provided the only major spawning area above the dam and that spawning occurred during the period between the last week in August and the last week in September. Based on this knowledge, an aircraft survey was conducted over the M'Clintock River system on August 28 to enumerate the actual spawning population. There were, however, no salmon sighted. Following this the programme was enlarged to include four additional aerial surveys of Michie Creek and one reconnaissance of the area lying upstream from the M'Clintock system. Although the latter included tributary streams of Marsh, Tagish and Bennett Lakes (Figure 1), no evidence of either live or dead salmon was obtained. The Lewes River Dam, a low-head structure near the outlet of Marsh Lake was open all season and careful observation indicated quite positively that it did not present an obstruction at the water levels encountered. This structure is the only known possible obstruction in the reach between the Whitehorse Rapids Dam and the spawning grounds.

Indian Fishery

In past years a local native has operated an aboriginal trap in the M'Clintock River. During the past season this was not done but two gill-nets were fished in the lower reaches of the river. The reported catch totalled only ten salmon which serves only to indicate that salmon reached the M'Clintock system.

Discussion

Although an accurate direct measure of delay to the migrating salmon was not obtained, the pattern and timing of migration as well as the observations made on behaviour and condition of fish at the development site indicate that the fish facilities operated satisfactorily. The fact that the migration pattern is not skewed; that 96 per cent of the migration took place in a 21-day period; that condition of the salmon remained good throughout the migration; that there was no evidence of spawning below the facilities; that there was a lack of injury and that there was an absence of any major accumulation below the barrier dam, all suggest that the salmon were not seriously interrupted in their migration.

Specific observations indicated that each unit of the fish facilities operated satisfactorily. Attraction into and movement through the fishway of salmon and grayling appeared to be good, the barrier dam apparently formed a complete obstruction to migration and there were no migration problems at the powerhouse collection facilities during 1959.

The failure to locate salmon on the known spawning areas above the damsite does not serve as proof of absence. It did, however, prevent any estimation of the success of spawning. The spawning ground survey may not have included all potential areas of the upper system, however, and utilization of areas other than Michie Creek may have occurred, possibly in other portions of the M'Clintock system itself. This possibility is suggested by the catch of salmon in the Indian fishery near the mouth of that system. The presence of relatively large numbers of juvenile spring salmon, progeny of the 1958 adult migration of which the observed spawning population totalled only 15, also suggests that spawning distribution is greater than is presently known.

There are a number of factors yet to be studied regarding passage of fish at the Whitehorse Rapids Power Development. These include the success of salmon spawning above the damsite; the pattern of upstream migration of species other than salmon; turbine mortality and the timing of downstream migration of the major species. Further investigation of these points will be required.